JOURNAL
OF THE
AMERICAN WATER WORKS ASSOCIATION

VOL. 33, NO. 11 NOVEMBER, 1941

Published Monthly
at Mount Royal and Guilford Avenues, Baltimore, Md.
by the
AMERICAN WATER WORKS ASSOCIATION
22 EAST 40TH ST., NEW YORK

The basic Mathews principle of a removable barrel containing all operating parts is now 75 years old. It cannot be improved upon, for the elbow and protection case are permanently in the ground, yet the hydrant can be repaired, replaced, overhauled, modernized, raised, or lowered, from above ground, with *no* digging. Note that the barrel screws tight into the elbow at (1) while a loose frost casing (2) allows it to be removed complete with main and drain valve and their seats (3).

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Published Monthly at Mount Royal and Guilford Avenues, Baltimore, Md.
Entered as second class matter April 10, 1914 at the Post Office at Baltimore, Md., under the Act of August 24, 1912. Accepted for mailing at a special rate of postage provided for in section 1103, Act of October 3, 1917; authorized August 6, 1918

Made in United States of America

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All correspondence relating to the publication of papers **should be addressed to**

Harry E. Jordan, Secretary
22 East 40th St., New York

$7.00 of Members dues are applied as subscription to the Journal
Additional single copies to members—50 cents
Single copies to non-members—75 cents

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Water Supply Facilities and National Defense

By John Edgar Hoover

IT HAS been a little more than two years since hostilities which were destined to have world-wide ramifications flared up across the seas. As nation after nation fell under the heel of aggressor nations, America watched, heeded, and plotted her course. From the beginning that course has been one of preparedness for any eventuality.

Less than one week after that indelible date of September 1, 1939, the President of the United States issued a directive designating the Federal Bureau of Investigation as the co-ordinating agency in all matters pertaining to espionage, sabotage, and other related national defense matters. At the request of the Army and Navy, the FBI immediately undertook an extensive program of surveying industrial plants having contracts to supply the armed forces with vital defense materials. Trained Special Agents of the FBI have thoroughly surveyed approximately 2,000 of these manufacturing establishments for the purpose of recommending suitable protective measures to the plant officials. In addition, over 24,000 copies of a confidential booklet, entitled *Suggestions for Protection of Industrial Facilities*, have been distributed to officials of industrial plants, public utilities, and transportation facilities, to whom this book is available upon request.

At the present time, with the official approval of the Director of Civilian Defense, the FBI is engaged in conducting courses of training

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A contribution by John Edgar Hoover, Director, Federal Bureau of Investigation, United States Department of Justice, Washington, D. C.

for the police of the Nation in order to assist them in knowing and performing their duties in the civilian defense program. The first detailed instruction in the operation of police in civilian defense work was given to the graduates of the FBI National Police Academy, who returned to Washington, D. C., during the week of October 6 to 11, 1941, for their annual re-training course. There are 627 of these local police officers who have received instruction in the methods of the FBI and have returned to their departments to conduct training schools for the other members of their organizations. As a part of these "FBI Civilian Defense Courses for Police" being conducted in key cities throughout the United States, instruction is given in the protection of public utilities which play such an integral part in defense activities.

The results of the FBI's preventive program have been eminently successful as attested by the negligible amount of sabotage committed in the United States thus far in this world crisis as compared with the corresponding period of the first World War.

In the face of this encouraging record, we must not be lulled into a false sense of security. The thrusts of the subversive agent must be met and thwarted at every turn. The methods of operation of the saboteur and the espionage agent are limited only by their ingenuity. Any point which, when damaged, would result in an impediment to the preparedness program is a possible object of attack, whether such impediment be in the form of desreased production or undermined public morale.

Vulnerability of Water Supply Facilities

It has long been recognized that among public utilities, water supply facilities offer a particularly vulnerable point of attack to the foreign agent, due to the strategic position they occupy in keeping the wheels of industry turning and in preserving the health and morale of the American populace. Obviously, it is essential that our water supply facilities be afforded the utmost protection. Of course, each facility presents its own peculiar problems which can be successfully coped with only by the adoption of appropriate protective measures after a detailed survey of the facility. There are, however, some general aspects of the problem to be considered in the undertaking of any protective program. In order that the problem may be approached intelligently, it is desirable to consider some of the more common methods of sabotage, for, then, many of the plant's vulner-

able spots will be immediately apparent. We must, for instance, guard against such possibilities as:

1. Damage to machines or equipment by breakage, manipulation, abrasives, chemicals or foreign bodies.

2. Damage to vital machinery, equipment or buildings by time bombs, gas explosives, incendiary bombs and devices, or by the use of other explosives.

3. Damage to power stations, transmission lines, transfer stations, switchboards or other key points of the power system.

4. Damage to materials being used for processing the water.

5. Damage to precision or technical mechanisms.

6. Bacterial infection or other pollution of water.

7. Damage to or theft of working plans, formulas or other confidential data.

8. Injury to personnel, including the introduction of contagious diseases.

9. Damage by arson, including undue negligence and existing fire hazards.

Personnel Considerations in Protection Against Sabotage

The personnel of a water supply plant should be regarded as the most important single factor in the protective system. Disloyal or disgruntled employees are in a better position to commit subversive acts than anyone not officially connected with the plant. On the other hand, loyal employees who have been properly instructed in their protective duties constitute the plant's greatest asset. Therefore, it is of paramount importance that all applicants be investigated carefully before employment, to establish their nativity, integrity, and patriotic tendencies.

One of the greatest dangers to overcome is the possibility of trespassers gaining access to the plant property. A suitable fence enclosing the entire plant area is a fundamental protective feature. This constitutes the plant's "first line of defense." This barrier represents concrete evidence to all that the management of the plant within is on the alert to prevent the malicious work of any would-be trespasser.

A strict identification system is essential to the protection of every plant. A badge worn in a uniform place on the outside of the employees' clothing is perhaps the most feasible and practical means of identification. If the system is to function properly, there must

be absolutely no exceptions to the regulation. It is suggested that an appropriate identification card be issued to each employee to augment the badge.

In one plant surveyed by the FBI, where an identification system to keep unauthorized individuals out of the plant was recommended, the officials did not deem this necessary inasmuch as each employee was required to punch a time card upon entering and leaving the premises. The fact that the time card did not operate as an efficient identification system was realized when it was called to the attention of the plant officials that a certain employee had been absent for a week and was receiving his pay because his time card showed he had been present. His salary had been delivered by the plant to a friend of his. It was an easy matter for the stranger to walk into the plant and punch his friend's time card without being identified as an intruder.

Additional Measures for Defense

Protective illumination, by depriving the saboteur and the spy of the cover of darkness, renders the plant's other protective measures effective day and night. The whole plant area, fence, and approach areas should be lighted so that any trespasser can be seen and readily identified at night. Unfortunately, the value of illumination as a protective feature has been sorely underestimated.

All confidential documents, such as processing formulas and blueprints showing water mains, should be kept in a vault or some other secure place. Such places, as well as those points where particularly vulnerable facilities are located, should be posted as restricted areas, and the persons having access to these areas should be limited to those actually having business therein.

The cause of interruption to the function of a water works is immaterial when considering the effect on the defense program. For this reason, it is just as important to eliminate natural hazards as it is to fortify the plant with physical protective devices. All unnecessary combustible and abrasive materials should be eliminated. Adequate fire fighting apparatus should, of course, be available. During one survey, the inspection of one building, which housed extremely confidential items, revealed that there was no fire fighting equipment available for extinguishing fires in wood, rags, paper, or other inflammable materials of a similar type. Such conditions as these in

water supply facilities constitute natural hazards which aid the saboteur in his mission of destruction.

The guard force is the backbone of any efficient protection program. The men selected for guard work should be intelligent and physically fit. In one survey conducted by the FBI, when it was suggested that the guard force submit written reports, the Agents conducting the survey were astonished when told that this would be impossible since most of the guards could neither read nor write. In another plant it was discovered that the average age of guards was over 64 years and that several of the guards were over 80 years old. Such conditions signify that the importance of a competent guard force has not been not been fully realized by the management of many plants.

In order that America may meet the challenge to world democracy, all of her vast resources must be brought into play and co-ordinated into a productive, well-balanced defense program never before realized in the history of this country. In this great undertaking, water supply facilities occupy a key position, and, therefore, it is essential that they operate without interruption.

Notes on Water Works Defense

By David S. Thomas and H. B. Foote

David S. Thomas: The first step to be taken in mapping out an emergency plan of operation is to keep accurate plans of all supply structures, together with their record of operation, all in duplicate, completely indexed and safely filed. Such records should include location and size of mains, hydrants and gate valves in such convenient form that they can be taken into the field by the emergency maintenance crews. No superintendent or employee should depend upon his memory for this information in lieu of keeping detailed records in duplicate, for after all the emergency may involve him.

It has been stated that the disastrous fire which followed the earthquake in San Francisco in 1906 might have been held to much smaller proportion if the fire chief had not been killed during the early stages of the emergency. The water system was rendered useless for fighting fire, due to the many breaks of mains in the distribution system by the earthquake. The fire chief had planned ahead for such a contingency by the construction of many cisterns throughout the mercantile district, but, unfortunately, did not keep any record of their location—depending upon his memory. Since he was the only one in the fire department who knew of their location, with his death, the fire fighting efforts were just as handicapped as if the cisterns were never built, all due to the failure to keep records in convenient form. Before leaving the subject, it must be pointed out that it is very essential that records be kept up to date, for records 95 per cent complete are practically worthless.

Regarding the distribution system, possibilities of failure during emergencies indicate that it should be so designed that no single

Some comments presented on May 23, 1941, at the Montana Section Meeting, Missoula, Mont., by David S. Thomas, Inspecting Engineer, Board of Fire Underwriters of the Pacific, Great Falls, Mont., and H. B. Foote, Director, Division of Water & Sewage, State Board of Health, Helena, Mont.

unit is dependent upon a single line or water works structure. This calls for duplication of pumping equipment, supply mains and elevated storage, preferably at widely separated points. No one section of the distribution system proper should be dependent upon a single artery. All industrial and mercantile areas should receive special attention in the way of reinforcement and duplication of supply mains and arteries.

Gate valves should be provided so that not more than 500 ft. of main in the mercantile or industrial areas, or more than 800 ft. in the residential sections would be affected by any break, accident or repair. Additional hydrants should be provided for service under the most severe conflagration conditions, which after all is a type of emergency that may confront every city and town. All hydrants, especially those along the main arteries, should have individual gates in the branches.

All valves in the distribution system should be inspected at least annually, and the larger valves more frequently. Hydrants should be inspected in the spring and the fall, after use in fires, during cold weather, and daily in the mercantile and industrial districts, during extended periods of severe cold weather.

Emergency maintenance crews should be so organized that they are quickly available at all times. Trucks should be provided for quick transportation of men, tools and spare repair parts. These trucks should be equipped with portable floodlighting equipment, portable pumps and power tools.

Emergency Sources of Supply

H. B. Foote: Any consideration of sources of water for emergency purposes may seem to be out of line since we are so accustomed to our familiar and apparently sufficient present sources.

Deliberately to step out and make a project of finding other water sources may seem like an academic activity, not directly, or in any practical way, in line with the usual day-by-day program. If one is to give any thought to the unusual, the emergency, or the catastrophe, however, this phase should be included in thinking and planning.

Perhaps the first place to seek such emergency sources is in the immediate vicinity of the present source. From this focal point a circle may be enlarged which eventually includes the total area of

the community and perhaps has a radius reaching out beyond the city's boundaries for some distance.

The usual studies of each potential source should be made and it may not be out of order to suggest that a record be kept of all the data accumulated. Facts pertaining to quantity, chemical quality, geology, sanitation and general availability should be obtained as opportunity affords. Included certainly should be a study of ways and means by which such waters as may be found can most economically be put into the distribution system.

Any need for treatment to make the water safe or more desirable should be thought out. Any changes in distribution or storage due to such change in quality, quantity or location of water source should be anticipated as far as possible.

Perhaps no one source can be found which in itself will be adequate. All the better, it would therefore appear, to have information about *all* possible sources.

An emergency may demand extra disinfecting equipment and material so that the usual orderly processes of water treatment will not be disrupted. Some have found the solution of this problem in hypochlorination if the period over which the emergency exists is not long or the volumes of water involved are not too large.

National Defense Council at Gloversville, N. Y.

By Robert M. Colt

THE Gloversville National Defense Council is a non-political, non-racial, non-religious and non-social body, composed of citizens from every walk of the city's life, organized to provide a central agency for the co-ordination, activation and administration of the broad scope of the city's rôle in national defense; to develop and sustain group mobilization; to function as a civil emergency board, and, as such, to organize the civil and business interests of the community to meet any contingency incident to social and economic adjustment resulting from national defense requirements and a potential national emergency. It also purposes to promote actively local social, economic and home defense mobilization; to provide accurate and official information to the citizens and to obtain for the Mayor of the City vital data on personnel and production, such as is being demanded by the state and Federal governments; to lead the city in a broad program of unification, co-ordination and co-operation with intelligent organization designed to meet a general problem of the present and future with calmness and efficiency.

The first act of the Gloversville National Defense Council was to organize for and take a population census of every citizen—man, woman and child—between the ages of 16 and 65. A questionnaire calling for 28 items of information, including place and date of birth, citizenship, health, present occupation, trade, business or profession, hobby, equipment, special training, education, languages spoken, military training, etc., was prepared. Distribution was made by 42 local organizations which provided ten members each from labor, patriotic, industrial, educational, civic, religious, social and fraternal

A paper presented on September 11, 1941, at the New York Section Meeting, Glens Falls, N. Y., by Robert M. Colt, Director-Secretary, Gloversville National Defense Council, Gloversville, N. Y.

groups, a total of 420 men and women who made a house-to-house canvass, returning over 16,000 questionnaires. The elaborate organization and statistical set-up necessary to accomplish this work need not be detailed. Suffice it to say that the activity of this group aroused the entire city so that everyone of its 24,000 population responded to the call of national defense.

From the information obtained from these 16,000 questionnaires the Council was able to present a true picture of the community's potential contribution to defense. Classified statistics showed that workers of 143 skilled trades were available, and that, broken down on the New York State vocational decimal plan, the list could provide not only skilled workers, but those known as "Professional," "Clerical," "Service," "Unskilled" and "Agricultural," who could eventually take the place, in business and industry, of those who are called to the service of their country.

Military and Defense Training

The questionnaire also showed that 2,795 men and 1,570 women had expressed a desire for military training. To carry out a program of this magnitude, of course, required a well-ordered organization. Using the information secured from the questionnaire, all men who had had military experience as commissioned or non-commissioned officers were called in. These men were trained in the new drill regulations, and, upon qualifying, were given commissions by the Mayor. The men who had registered for this service were then organized into a Citizens' Military Regiment, consisting of three battalions of four companies each. Since last October, the regiment has been receiving training, each battalion drilling one night a week. Once a month, the entire regiment assembles for regimental drill. The group is designed to serve as a reservoir of "trained citizens," to be used as emergency guards of municipal water and power supplies, public utilities, local mills and factories, and for city defense purposes.

Other groups of 25 men each are taking training with the fire department, with the police department, in first aid and emergency work with the American Red Cross, etc. When these various groups—military, fire, police and first aid, etc.—are fully trained the community will have available a trained force capable of meeting practically any emergency, when called upon to do so by the constituted authorities.

The women's regiment has been organized and is being trained under competent women instructors. In addition to military training which will enable them to operate as a trained unit, rather than as a group of individuals, they will be trained in first aid, in ambulance, truck and motor car driving; in air raid observation; in welfare and food distribution work; in care of women and children who may be evacuated, including education, health, sanitation, housing, etc. Women are of ever increasing importance in the vast scheme of national defense, and it is felt that they will not fail to come forward and offer themselves in the service of their country, for without the unqualified moral and physical support of the women, the government will be unable to make fully effective the plans now in the making to provide a real defense for this country.

Vocational Training and Co-operative Activities

Next, the population questionnaire showed that over 1,500 young men and women, between the ages of 18 and 25, desired vocational training in various trades and businesses. These are being absorbed through the vocational training schools of the City's educational system and the National Youth Administration, with the assistance of the county supervisors and the Federal government, through the medium of a federal project.

The Medical Group includes in its personnel 42 local medical, dental and veterinary doctors, and 100 pharmaceutical, chemical and medical auxiliary workers, including, of course, registered nurses and the American Red Cross first aid group. Hospital facilities have been inventoried and classified and workers organized and trained for instant mobilization in any local emergency.

Farmers, dairy men and other food producers and distributors have been organized to provide for emergency food supplies for the city, should the normal supply be interrupted from any cause. This group co-operates with the State Emergency Defense Agricultural Committee.

Veterans Emergency Group

World War veterans of Gloversville, in an organized, fully staffed and trained unit of over 400 men, are available to serve the community in any emergency. This group has been so trained and rehearsed that, upon hearing a special alarm of "6-6-6" on the city fire siren and four factory whistles in other parts of the city, they can

be assembled at 23 posts in various geographical points in the city, day or night, in six minutes. Upon such an assembly, the commanding officer of each post telephones the chief mobilization officer, who is stationed in the City Hall with the Mayor, Chief of Police and possibly the Sheriff. Each post, as it calls, is given direct orders to report, by automobile, to a certain location for guard or necessary duty. Plans protecting the vulnerable city services, public utilities, power dams, etc., have been mapped out for any possible contingency, and the organization work practiced. The equipment of this unit consists of ambulances, fifteen 5- and 10-ton trucks, picks, shovels, sand bags, rope, ladders, stretchers, etc., which are positively available within fifteen minutes from the time of the alarm. Accompanying any emergency call are doctors, nurses, hospital orderlies, stretcher-bearers, etc. In an emergency all traffic lights show "red," through which the veterans emergency group may proceed in responding to a call.

Last October, this group of trained veterans was formally turned over to the Mayor and Common Council of the City. This force is being trained to patrol and police the city, under constituted authority, should it become necessary at any time to transfer the police force to other communities in an emergency, as now provided for by state law.

Business and Industrial Mobilization

The work of the Business and Industrial Mobilization Committee was to conduct an industrial survey to make available for the state and Federal governments, the labor and industrial resources of the city; to include a general line of products, facilities, space, equipment, possible expansion and available labor by skills; to stimulate local manufacturers to secure government contracts, so as to utilize the entire productive capacity of their plants to the extent permitted by space, idle machine hours and labor available; to assist small local manufacturers in being brought into the industrial defense program by receiving contractual work from the prime contractors. This survey was made and a complete report on 58 mills and factories turned over to the Division of State Planning, on January 28, 1941. To the Committee is turned over all information, received from state and Federal sources, and having to do with national defense industrial requirements. Such information is immediately transmitted to the

various types of business and industry to which it applies, and every assistance is given by the Committee in the making of bids, and in finance, labor, and final production. As required by the state and Federal governments, the Committee will secure and prepare information in the interest of national defense.

Housing Survey and Youth Work

The scope of the Gloversville plan is enlarging constantly, and, just now, in addition to the foregoing, a survey of vacant housing and vacant rooming is being made. The primary purpose of this is to locate and list all vacant houses and rooms which may be available to care for workers in national defense who may come to the city, and, further than that, to have available, at all times, information which will permit and provide for the evacuation of twenty million or more persons from the Atlantic seacoast.

Municipal sub-divisions, such as police, fire, water, streets and engineering, public health and education, welfare, etc. have been united in a correlated program. Air raid precautions, air raid protection and air warning services are being organized and charted, showing how all work in co-operation, under a control center, in an emergency. Boy and Girl Scouts will be brought into the picture and trained in airplane observation, courier service, salvage service, etc. Incidentally, in the past twelve months, England saved $7,500-000 in salvage of materials through the work of its youth.

Importance of Local Defense Organization

There is not space to enlarge upon the all-out effectiveness of any national defense council, but there is space to say that an active defense council, led by and made up of men and women of vision, imagination and energy, is needed in every community of the United States. The defense council organization is the force which will "make the wheels go 'round" in the accomplishment of the work necessary to be done due to the grave situation in which this country finds itself. To national defense councils the state and Federal governments look for that which will educate, stimulate and awaken its citizens, and a careful watchfulness for the forces operating among us who would destroy this country. To put down subversive doctrines, to teach those they seek to ensnare, to help worthy aliens to become citizens and to prevent unworthy aliens from doing so are

important duties. In all this, calm sane procedure must be available, operating through the constituted authority of the city, state and Federal governments.

It must be pointed out again that activities such as have been described, kept constantly before any community, and participated in by all patriotic citizens, will arouse in the hearts and minds of all the people of a community, the necessity of awakening to the realization that "smug complacency" and "spineless inactivity" have no place in a program of national defense. Constant, meaningful demonstrations of these activities have a salutary effect upon certain groups and aliens, who have not the good of this country at heart. It must be said, however, that, as momentous events follow, as they most certainly will, it will be necessary to enlarge the scope of present activities to include those necessary to carry out all the requirements of national and civil defense.

Regional Water Supplies

By Abel Wolman

THE problem of providing water supply and other utility services to people living within multiple political boundaries has become increasingly acute in the United States as well as in almost every other growing country in the world. The provision of public services to ill-defined areas, generally described as regions, creates radically different problems and solutions, of law, finance, administration and engineering, than are familiar in orthodox municipal functioning. One of the major reasons for these difficulties lies in the fact that the region of present and prospective service is frequently difficult to delimit and equally difficult to co-ordinate with the existing political subdivision of municipality, county and state.

For this reason, the writer makes no effort to define either the areas or densities of populations normally to be included in a water supply service region, because no constant and inflexible definition, which would fit the multiplicity of conditions in this country, appears to be feasible. The areas and populations which normally may or should be considered as a unit range, for example, from the smaller sanitary district in Anne Arundel County, Maryland, of 10 or 20 thousand people, to a Delaware River Basin or an Ohio River Basin, covering 200,000 sq.mi. and a population approaching 20 million. At both extremes, problems of unified water service are presented every day in more striking and difficult forms. In none of the areas, does simple adherence to existing political units for functioning promise anything but inefficiency, waste and extravagance.

This paper is devoted, therefore, to a discussion of some of the causes for the emergence of regional supply problems, some of the service difficulties which have arisen as the result of such regional growth, some of the solutions which have been proposed in this coun-

A paper presented on June 23, 1941, at the Toronto Convention by Abel Wolman, Professor of Sanitary Engineering, The Johns Hopkins University, Baltimore, Md.

try and elsewhere and some reflections on the unsolved difficulties which confront us for the immediate future.

Changing Concentrations of U. S. Urban Populations

One of the most striking characteristics of population change in the United States has been disclosed and emphasized by the Census results of 1940. As many observers had already anticipated, the decade from 1930 to 1940 showed a decided halt in the rapid growth of our American cities. Prior to 1930 virtually every decade showed that these same cities had population increases generally at a rate in excess of that for the population of the country as a whole.

In all of these Census data, the cities referred to are those defined as "political" cities, i.e., areas (and populations) within the political boundary of the municipality. As one shrewd observer has recently put it, "The Census taker has always counted people in the places where they sleep, and not where they work and spend their waking hours." This method of Census taking has failed to credit, therefore, the populations of "actual" cities to the "political" cities. The "actual" city is that aggregation of people which works in or benefits from the "political" city, but which lives beyond its boundaries, and is independent of its political jurisdiction.

Another significant finding in the 1940 Census is that many of the largest cities of the country showed a decrease in population, or a comparatively insignificant gain, from 1930 to 1940. For example, 412 cities with a population of 25,000 or more and an aggregate population of 52,536,000, in 1940, showed a gain of only 5 per cent since 1930, in contrast with a gain of almost 26 per cent in the previous decade. Furthermore, the rate of growth of cities in 1930–40 was less than that of the country as a whole, which showed an increase of 7 per cent. Exactly the reverse was the case in the previous decade, when the increase for the cities was 25.5 and for the country as a whole, 16.1 per cent.

All of these facts would appear superficially to indicate that the trend toward urbanization, so striking in past decades, is coming to a stop. Although the trend was non-uniform in the 1930–40 period, since the southern tier of states showed the greatest urban increase, an actual population decrease occurred in 5 of the 10 largest cities of the United States—Philadelphia, Cleveland, St. Louis, Boston and Pittsburgh. Also, the increase in Chicago was practically negligible. All of these figures again refer to changes in "political" cities.

Trend Toward Urbanism Unchecked

A more careful scrutiny of the census figures, however, does not support the thesis that there has been a stop in the trend toward urbanism in the United States. What has happened has been a decline of the rate of population growth within artificially defined "political" areas, which are not, and incidentally have not been for many years, true economic, service or fiscal units. Only the strong psychological bonds which tie us to historical political boundary concepts give any validity to the current assumption that the true city is actually declining in population. As a matter of fact the true city everywhere in the United States increased in population in the last decade.

What the data later presented herein will show is that a new unit for service is and has been patiently awaiting political recognition for at least two decades in American history. The Census taker has defined it as "the area encompassing a city or group of cities and their environs, with a population of about 150 people per square mile."

Recognizing new regional groupings of dense populations, it would appear that, instead of having stopped, the trend towards urbanism has actually increased. The more significant fact is that "America's growing big cities accounted for nearly all of the nation's increase during the last decade," as evidenced by the fact that almost 63 million people, or 47.8 per cent of all the residents in Continental United States, live in 140 metropolitan areas or in the "actual" cities of the country. This was 8,205,058 more than lived in such areas in 1930, whereas the total population increase of the Nation, in this same interval, was only 8,894,229. The records of some of the largest of these areas is shown in Table 1, and of some of the significant smaller types in Table 2.

Causes of Shifts in Population Growths

The causes of the shifts in population growths which these tables disclose give some basis for adjustments of utility servicing policy. The changes that have taken place point to the conclusion that the water supply purveyor will have to lift his vision from old Main Street to a new city made possible by technological change. No longer can the utility officer restrict his operations to a city defined by the standards of 1900 and controlled by fiscal and engineering units resulting from the practice of that same period.

TABLE 1

Growth of Ten Largest Metropolitan Areas

RANK	AREA	1930	1940
1	New York	10,902,424	11,690,520
2	Chicago	4,364,755	4,499,126
3	Los Angeles	2,318,526	2,904,596
4	Philadelphia	2,847,148	2,898,644
5	Boston	2,307,897	2,350,514
6	Detroit	2,104,764	2,295,867
7	Pittsburgh	1,953,668	1,994,060
8	San Francisco	1,290,094	1,428,525
9	St. Louis	1,293,516	1,367,977
10	Cleveland	1,194,989	1,214,943

TABLE 2

Examples of Growth in Some Smaller Metropolitan Areas

	POPULATION		PERCENTAGE INCREASE
	1930	1940	
Baltimore, Maryland			
Metropolitan district	949,247	1,046,692	10.3
Within city limits	804,874	859,100	6.7
Outside city limits	144,373	187,594	29.9
Knoxville, Tennessee			
Metropolitan district	135,714	151,829	11.9
Within city limits	105,802	111,580	5.5
Outside city limits	29,912	40,249	34.5
Wilmington, Delaware			
Metropolitan district	163,592	188,974	15.5
Within city limits	106,597	112,504	5.5
Outside city limits	56,995	76,470	34.1
Spokane, Washington			
Metropolitan district	128,798	141,370	9.2
Within city limits	115,514	122,001	5.6
Outside city limits	13,284	19,369	45.8
Salt Lake City, Utah			
Metropolitan district	184,451	204,488	10.8
Within city limits	140,267	149,934	6.9
Outside city limits	44,184	54,554	23.4

The causes which are most frequently suggested are few in number. Their real importance changes almost from year to year, with the exception of one or two which have been dramatic in their impact and possibly permanent in their influence.

Prior to 1940 much pessimism was engendered by the declining birth rate of the 1930–40 period. Perhaps some of this pessimism is less warranted today than appeared to be the case even a year ago. The trend toward a declining birth rate is now rapidly reversing itself. For example, in Maryland, presumably typical of many other states, the excess of births over deaths was considerably greater in the first six months of 1941 than for the corresponding period of 1940. In that period 4,529 more births than deaths were reported as against 2,830 in 1940, and 3,538 in 1938.

Apparently when people can support children they tend to have them. This is an axiom which has prevailed for many thousands of years and which appears to be coming again into its own in this country. It is too early to estimate its total effects in reversing the trends of the last decade, but it is certainly wise to assume that all of the calamities anticipated from the declining birth rate of the past ten years are not as imminently threatening as they appeared even only a year ago.

A more significant reason for declining population growth is the cessation of immigration. This factor, coupled with the long economic depression, did much to make the experience of the last decade perhaps less significant and typical of the fate of populations in the United States than has currently been assumed. Technological changes in industry, such as the great shift from coal mining to oil use, also accounted for much of the geographical shift in population.

Perhaps the most significant factor dominating the shift in population aggregation in any area was the introduction of the automobile as a new method of transportation. The automobile "revolution" probably accounts for the most significant population changes in this country now, as did the equally important "industrial" revolution in the early Nineteenth Century. The widespread use of the automobile has made the political boundary of the old city an anachronism. The automobile has expanded the practicable living areas of people and has forced the development of a wider service area than we were accustomed to consider either practicable or necessary 30 or 40 years ago.

Problems of the New City and the New Region

These new unnamed areas of population extension have seriously disturbed the historic comparative stability of the old city. Everywhere one is confronted with the problem of the decentralizing of the population in the old city, of the declining central business area or core of the old city and of the consequent increasing loss or obsolescence of the major utility investments in these old areas. These losses are multiplied by the development of expanding service areas requiring more costly utility servicing.

Some of these difficulties are apparent in such an area as the Baltimore Metropolitan District in Maryland. This area, adjacent to the old City of Baltimore, is typical of dozens of others throughout the United States. The Baltimore County Metropolitan District, as defined by the Census Bureau, covers 180 sq.mi. within which 150,000 people live. The servicing of such an area should be contrasted with that of the city, itself, with a land area of only 79 sq. mi., in which 860,000 people reside. Obviously, the economics and the engineering of the servicing of two such areas, one with a density of 830 and the other of 10,890 persons per square mile, cannot be considered upon the same plane.

In the Baltimore County Metropolitan District, however, we have an unnamed city, without a political boundary, which is as large or larger in population than San Diego, Kansas City, Des Moines, Bridgeport, Jacksonville, Albany or Scranton. Although it lacks even a name, it is none-the-less a city, requiring modern facilities for its continued existence. As a child of the City of Baltimore and generically related to it, it still clings to Baltimore by the proverbial "silver cord." Without the industrial and commercial opportunities of Baltimore itself, this new and rapidly growing unnamed city could not exist.

Aside from the fact that, generally throughout the United States, this new city has little or no machinery for utility servicing, other than the casual, impromptu and unorganized type, responsive to the pressures of immediate needs, with no plan or rule for the future, these areas tend to drain the strength and to sap the resources of the old city. In most areas of this type, little or nothing is being done except to create a tremendous legacy of problems for future generations. The tempting attraction of present lower tax rates merely veils the less tempting future of skyrocket tax rates to correct the mistakes of today.

These problems, therefore, offer a real challenge to the water purveyor and to every other utility servicing unit. They are not and will not be met by the mere adherence to the policy of restricting extensions to areas outside of the old "political" city. People will live how and where it pleases them to live. The utility, public or private, will be expected to service them. There is no unwritten law that the unit costs of service within a political city must dominate and restrict the changing habits and opportunities of the American people to spread out for more spacious living. Besides, there is a question of which unit costs should control, those of New York City and Richmond, among the most congested, or those of Los Angeles and Salt Lake City, among the least crowded.

The great variation in service requirements per unit of population and per unit of area is demonstrated by the data shown in Table 3. These data, collected by the writer in connection with the Richmond, Virginia, annexation case, cover a reasonably wide group of utility service areas. They show how ridiculous it is to speak of water service as more economical in one restricted group of political units than in another.

If it requires only 7.6 ft. of water main per person in Baltimore city and 24.8 ft. in the Washington Suburban Sanitary District, and both agencies are in sound financial condition, which unit should be the criterion of economic validity for the enlarged service area of the future? It may be surmised that the wishes of the public as to a way of life will prevail rather than an artificial criterion, which in itself is already so highly variable from place to place as to provide no basis for decision.

For the type of growth so far discussed a limited number of solutions have so far been proposed. Virtually none of them offer complete solutions. None of them have been generally applied nor have any been eminently successful. They are listed, however, for comment and as a background for later reflection.

Annexation

One of the best known devices for meeting the problem of metropolitan areas has been by annexation. Owing to the political difficulties involved in such a process, however, little or no advantage has been taken of this device during the past ten years. As long as our present philosophy persists, under the stress and strain of fiscal difficulties, of withdrawing the old city more and more into itself, no great hope may be held out for the more general use of this device.

TABLE 3

Variation in Service Requirements per Unit of Population and per Unit of Area in Typical U. S. Cities

PLACE	POPULATION SERVED	AREA (LAND ONLY)		POPULATION SERVED PER		MILES OF DISTRIBUTION MAINS	NUMBER OF FIRE HYDRANTS	NO. OF HYDRANTS PER MILE OF MAIN	FEET OF WATER MAIN PER			TOTAL NUMBER OF SERVICES	NO. OF SERVICES PER	
		Sq. Miles	Acres	Sq. Mile	Acre				Hydrant	Acre	Person		Mile of Main	Acre
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Davenport, Ia.	60,751[1]	18.07[1]	11,565	3,362[2]	5.3	122.0[2]	1,211[2]	10.0[2]	528	56	10.6	—	—	—
Harrisburg, Pa.	80,500[3]	6.19[1]	3,962	13,000	20.3	125.0[3]	1,420[3]	11.35	465	166	8.2	24,700[3]	197	6.23
Rockford, Ill.	85,864[3]	11.74[1]	7,514	7,300	11.4	200.1[3]	1,482[3]	7.41	712	141	12.4	20,788[3]	104	2.76
Little Rock, Ark.	87,000[4]	17.75[1]	11,360	4,900	7.6	225.35[4]	958[4]	4.26	1,240	105	13.7	17,750[4]	79	1.56
Altoona, Pa.	93,000[3]	8.64[1]	5,530	10,780	16.8	196.0[3]	3,885[3]	1.98	266	185	11.0	20,000[3]	102	3.62
Pasadena, Cal.	93,900[5, 6]	—	—	—	—	338.0[5]	1,664[5]	9.38	563	—	19.0	26,079[5]	77	—
New Rochelle, N. Y.	100,000[3]	—	—	—	—	240.0[3]	1,700[3]	7.08	745	—	12.7	14,000[3]	58	—
Sacramento, Cal.	118,808[4]	13.71[1]	8,774	8,630	13.5	247.15[4]	1,666[4]	6.75	782	160	11.8	29,828[4]	121	3.40
Cambridge, Mass.	120,000[3]	6.54[1]	4,186	17,376[1]	27.1	150.0[3]	1,200[3]	8.0	660	190	6.6	15,000[3]	100	3.58
Albany, N. Y.	135,000[3]	18.87[1]	12,077	7,150	11.2	269.4[3]	2,037[3]	7.55	700	118	10.5	26,912[3]	100	2.23
Springfield, Mass.	149,900[1]	31.70[1]	20,288	4,729	7.4	301.0[7]	—	—	—	78	10.6	—	—	—
Norfolk, Va.	157,000[4]	28.00[1]	17,920	5,620	8.7	384.0[4]	1,444[4]	3.76	1,402	113	12.9	29,984[4]	78	1.67
Richmond, Va.	187,839[8]	22.99[8]	14,714	8,160	12.7	386.52[8]	2,542[8]	6.58	789	136.4	10.7	42,963[8]	111	2.92
Tulsa, Okla.	165,000[4]	21.60[1]	13,824	7,630	11.9	393.0[4]	1,313[4]	3.34	1,580	150	12.6	29,800[4]	76	2.15
Oklahoma City, Okla.	175,000[3]	30.35[1]	19,424	5,770	9.0	330.43[3]	1,738[3]	5.26	1,002	100	11.1	33,538[3]	102	1.72
Hartford, Conn.	213,000[3, 9]	15.88[1]	10,163	13,400	21.0	422.1[3]	3,158[3]	7.50	704	219	10.5	27,116[3]	65	2.66
Syracuse, N. Y.	228,000[3]	25.34[1]	16,218	9,000	14.0	376.7[3]	5,004[3]	13.29	398	123	8.7	41,781[3]	111	2.57
Dayton, Ohio	230,000[3]	18.13[1]	11,603	12,680	19.8	304.7[3]	2,928[3]	9.61	548	138	7.0	48,715[3]	160	4.20
Akron, Ohio	250,000[3]	37.60[1]	24,064	6,650	10.4	601.0[3]	5,176[3]	8.61	613	132	14.0	53,800[3]	90	2.24
Columbus, Ohio	312,000[3]	38.46[1]	24,614	7,520	11.8	582.0[3]	4,042[3]	6.95	760	125	9.9	61,900[3]	106	2.52
Louisville, Ky.	330,000[3]	35.98[1]	23,027	8,110	12.7	678.0[3]	3,000[3]	4.43	1,191	156	10.8	65,064[3]	96	2.82
Average	160,598	21.45	13,728	8,514	13.3	327.26	2,378	7.15	782	136	11.2	33,143	102	2.87

Baltimore, Md.	868,988[10]	78.72[11]	50,381	11,100	17.3	1,246.6[12]	9,120[12]	7.32	722	131	7.6	201,377[12]	162	4.00
Baltimore County Metropolitan District	130,000[13]	181.0[14]	116,000	718	1.12	289.6[14]	1,209[14]	4.17	1,262	13.2	11.7	14,969[14]	52	0.13
Washington Suburban Sanitary District	85,000[4]	105.0[15]	67,200	810	1.27	400.0[4]	3,600[4]	9.0	586	3.1	24.8	21,150[4]	53	0.31
1924 Average of 63 Cities in the United States							1 to 3[16] per Acre	9.5[16]	558[16]	—	—	—	—	—
1925 Average of 294 Cities (Pop. 15,000 or more) in U. S. & Canada							12 per[17] 1,000 Persons	8.5[17]	620[17]	—	7.5[18]	—	—	—

[1] United States Census—1930.
[2] KING, F. H. The Spacing of Fire Hydrants. Jour. A.W.W.A., **15**: 224 (1926).
[3] *American City*, 1934–35 Series.
[4] *American City*, 1939 Series.
[5] Pasadena, Calif., Annual Report for 1935–36.
[6] Population includes metropolitan district; that of city itself is only 45,354.
[7] NEWSOM, REEVES AND ALDRICH, E. H. Service Lives of Water Mains. Jour. A.W.W.A., **31**: 1625 (1939).
[8] 1938 Report of Department of Public Works of Richmond, Va.
[9] Population includes that of adjacent towns.
[10] Maryland State Department of Health figures.
[11] Baltimore City Planning Commission figures.
[12] Baltimore City Bureau of Water Supply figures, as of Jan. 1, 1939.
[13] Estimated by Chief Engineer of District, as of Jan. 1, 1939.
[14] BALLARD, W. T. 1937 Report to Commission.
[15] 1939 Proceedings of Maryland-Delaware Water and Sewerage Assn.
[16] TURNEAURE, F. E. AND RUSSELL, H. L. *Public Water Supplies*. John Wiley, New York (3rd ed., 1924), p. 707.
[17] *Manual of Water Works Practice*. American Water Works Assn., New York (1925), pp. 315–16.
[18] Calculated.

It is important, however, to refer to one of the most recent annexations in this country, because of the recognition by the courts, in the annexation procedure, of the dramatic problem of the old city.

In the case of Henrico County *v.* Richmond City, Virginia, the following excerpts from the opinion of the majority of the Annexation Court, of January, 1940, shed interesting light on the problems here discussed. These opinions have since been confirmed by the highest court of the State (on June 9, 1941). Portions of the opinion are listed at some length because this happens to be the first important annexation to a large city in almost fifteen years.

"Many people in the territory proposed to be annexed derive their living directly from the City of Richmond. Many more of such people obtain their living indirectly from the City of Richmond. The compensation and remuneration, received by the latter for services rendered, goods purchased and other things, originated in the City of Richmond as earnings of persons employed or in business there, but who reside in the territory proposed to be annexed. Like considerations are expressed in the case of Alexandria *v.* Alexandria County (117 Va. 230) in which, speaking for a unanimous court, Judge Cardwell said:

" 'The people in Rosemont, Braddock Heights, Cottage Park, Park Addition, in Alexandria County, and West End in Fairfax County, market, shop and transact their business in the City of Alexandria and many of them are employed in the city. They attend the churches, places of amusement, participate in the social life of the city, and are, practically, as closely connected with the city life as are the people residing within the city's boundaries. They use its streets, electricity, gas, water and telephones furnished from the city; being without police or fire protection; the police department and the fire department of the city have always responded to calls for assistance from these outlying sections. In other words, the people in these outside localities enjoy in a large degree many of the benefits of the city without having to bear any of its burdens, a large portion, if not a majority of them, having moved from the City of Alexandria within the past 20 years'. . . .

"This condition of affairs which justified the Supreme Court of Appeals in reversing the Circuit Court of Alexandria and decreeing the annexation of the territory proposed to be annexed, may be likened, in rural parlance, to a well-fed milk cow whose head is feeding from the manger, which is in the City of Richmond supplying the feed, but

whose body is largely in the County of Henrico, and whose milk is yielded and drawn in the County of Henrico. Continuing the analogy, it would seem more desirable to have the whole cow under one jurisdiction that she might be properly looked after, nourished, stabled and cared for, and if veterinary services be needed, instead of having two veterinarians, one for the head and one for the body, not always working together or in harmony, have but one veterinarian, whose skill and ability would best promote not only the particular, but the general welfare of the cow. . . ."

TABLE 4

Date and Area of Successive Annexations by Richmond, Va.

Exclusive of 1941

DATE	POPULATION	AREA ANNEXED	TOTAL AREA AFTER ANNEXATION
		sq. mi.	*sq. mi.*
1742	250*	0.20*	0.20*
1769	574	0.54	0.74
1780	684	0.34	1.08
1793	4,384	0.41	1.49
1810	9,785	0.91	2.40
1867	38,710	2.50	4.90
1892	83,000	0.38	5.28
1906	105,000	4.45	9.73
1910	127,628	1.02	10.75
1914	145,244	12.24	22.99

* Original city limits.

From "A Report on City Growth and City Boundaries for Richmond, Va., February, 1939," by Harland Bartholomew and Associates, City Planners, St. Louis, Mo.

"We live in days of multiplied necessities. The luxury of an earlier generation has become the necessity of the present generation and in turn, the luxuries of the present generation may, in a few years, become the necessities even of the present generation and certainly of succeeding generations. To meet this condition at the Capital City of Richmond, the Queen of the South, with its consequent growth, its larger financial and commercial life, it would seem that a unified service with larger financial resources would best promote the health of citizens of the City of Richmond and of the territory proposed to be annexed, and would provide better sanitary, police,

fire and school service, all of which would benefit ultimately the territory proposed to be annexed.

"Mass production is the order of the day, and it seems to be beyond question that to meet multiplied and increasing needs of the people, there must be ample financial resources, at present apparently beyond the means of the people presently residing in the territory proposed to be annexed. Particularly does this seem so in reference to the ability of the territory, proposed to be annexed to furnish an adequate supply of water for the citizens in such territory. . . ."

The court, therefore, epitomizes the problem of the metropolitan area briefly and appropriately as the problem of maintaining the "well-fed milk cow." The City of Richmond was granted the right of annexation and thus continued its long history of meeting the problems of expanding population growth, periodically escaping its political boundaries. Its annexation history is shown in Table 4.

As already indicated, however, virtually few cities any longer make use of this device, because of political, psychological or fiscal reasons. As a mayor of one of our largest cities recently put it: "In our late annexation, we took in a lot of nice people, but not much money!"

The annexation method still remains, however, theoretically at least, one of the most satisfactory devices for meeting the problem of the expanding metropolitan area. Its use should be revived.

Metropolitan Districts

The metropolitan district device for particular functions, generally of a utility nature, has been very successful in this country as an intermediate stop-gap and temporary avoidance and postponement of a solution of the deeper problems of general administrative power and control. A long list of examples in metropolitan district servicing of water supply, sewerage, refuse disposal, etc., facilities testifies to the usefulness of this particular structure.

Certainly the operations of such districts as the Chicago Sanitary District, the Washington Suburban Sanitary District, the Baltimore County Metropolitan District, the Greater Vancouver Water District, Vancouver and Districts Joint Sewerage and Drainage Board, the Omaha District, Greater Winnipeg Water District, Passaic Valley District, East Bay Municipal Utility District and the Minneapolis-St. Paul Sanitary District have done much to afford utility service over several decades in areas which would have been throttled without them. They have not, however, provided the kind of generalized

political and managerial structures which are becoming increasingly essential for all of the areas which they encompass. In other words, each of these districts is superimposed upon an area for the performance of specific functions which will be only part and sometimes only a small part of the service necessities of the area. The hybrid administrative management, which, therefore, often results, is not only costly, but does not offer a permanent solution to all of the underlying problems of public service in the area.

In some of these regions servicing is provided by a sanitary district, virtually sitting astride 25 or more municipalities. In such organizations, the county, the state, the municipalities and the district exercise multiple public functions, loosely co-ordinated, through multiple public officials, all of whom unconsciously, but none-the-less strenuously, insist on postponing the day of simplifying and consolidating the administrative structures, which the population growth and the development of the area obviously have made necessary for the most economical and efficient service.

TABLE 5

Variations in Types of Metropolitan Districts

NAME OF DISTRICT	DATE OF CREATION	AREA	POPULATION 1940	CAPITAL EXPENDITURES	POPULATION PER SQ. MI.	CAPITAL EXPENDITURES PER CAPITA
		sq. mi.				
Passaic Valley Sewerage District	1902	80	1,100,000	$23,102,000	13,750	$23
Washington Suburban Sanitary District	1918	114	105,000	17,000,000	921	162
Sanitary District of Chicago	1889	443	4,700,000	256,000,000	10,600	51
Minneapolis-St. Paul Sanitary District	1933	100	778,000	15,700,000	7,780	20
Greater Winnipeg Water District	1913	52	284,000	17,400,000	5,500	60

These metropolitan districts are synonymous in name only and widely varied in character. In some instances, they provide limited but major engineering structures, as in the Chicago Sanitary District, while in others, they provide service from the house to the final

discharge, in water supply, sewerage, and refuse disposal, as in the Washington Suburban Sanitary District. These variations are exemplified in random samples tabulated in Table 5. None, of course, have met the collateral problems of all public services, such as schools, streets, roads, police, fire department, etc.

The metropolitan district remains a realistic concession to providing the minimum utility services essential for modern living. It does not and cannot meet the broader issue of universal facility provision. The latter still staggers under the weight of multiple political units.

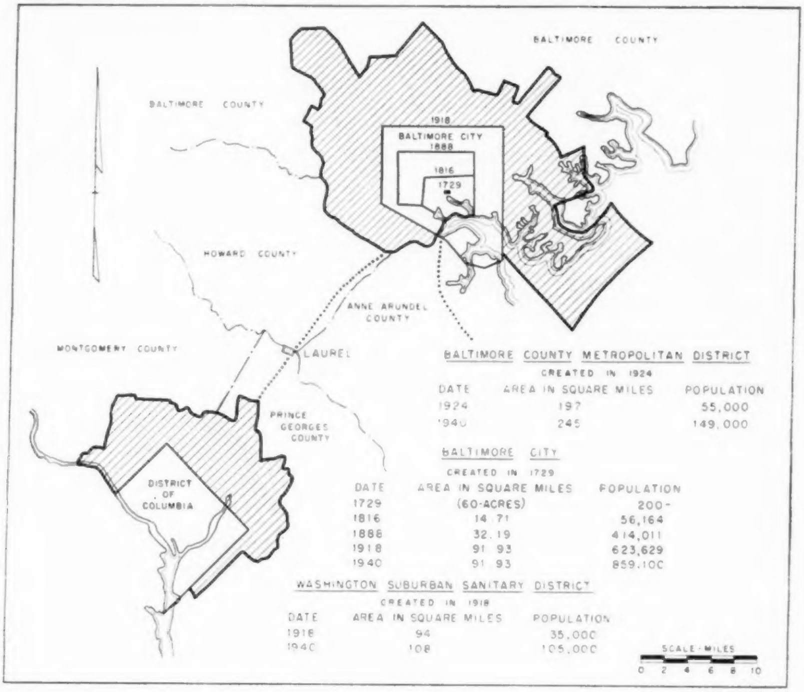

Fig. 1

Figure 1 illustrates how these issues have been met in Maryland by both the annexation and metropolitan district methods. The real solution is still far off, even though the problem is already acute.

The Public Authority

In the struggle to develop a more satisfactory device for meeting the stresses and strains of the area in question and of the more widespread regional area, the so-called public authority has been

developed in recent years as an instrumentality for handling the functional difficulties of these growing areas with common interests. The more familiar types are the New York Port Authority, the T.V.A., the Lower Colorado River Authority and multiple proposed authorities in Pennsylvania, Maryland, Alabama, California, and other states.

Such authorities have arisen in this country largely in the post-depression period and frequently in the effort to escape future fiscal problems and difficulties which plagued the American city from 1932 to 1940. These semi-independent corporate entities of a public ownership type have almost the same usefulness as the metropolitan district organization and somewhat the same disabilities. In no instance of which the writer is aware has this type of authority had more than a limited number of functions, important to perform, but by no means sufficiently inclusive to solve the problem of the regions involved. They will obviously continue to provide important services, but they cannot be considered as substitutes for a more general political solution of the problem of utility servicing of wide regions.

These same types of semi-independent authorities have a long and a reasonably successful history abroad. There too, they have been neither strictly governmental nor private, although their form and their function have differed from country to country. Virtually all of them in England, France, Germany and the Netherlands have been created for specific functional purposes. In all these countries, although their number has been increased, the problem of regional administration is still unsolved. As one French official recently commented in a national conference on utility servicing on a regional basis, the fear still persists that the creation of states within states for the purposes discussed still dominates and restricts the search for answers.

Miscellaneous Devices

Many complicated, unwieldy and relatively unsuccessful additional methods have been suggested to solve metropolitan and regional problems. They are merely mentioned here, since they offer less hope of curing administrative difficulties permanently than those forms already discussed. Some of them are:

1. Retention of present city limits and levy of taxes upon county residents for services rendered by the city.

2. City occupancy tax upon all salaries, to be waived upon salaries of all residents within the city limits.

3. Planning control in congested county areas by the adjacent city.
4. Voluntary boards of control over broad regions and their problems.

Unsolved Problems

A careful review of the principles, policies and practices here and abroad leads to the pessimistic conclusion that no real formulas for meeting these problems have so far appeared. In every country, whether totalitarian or democratic, the form of new political structures necessary to meet the problems discussed has not yet been crystallized. In the more centralized countries, of course, some progress has been made in superimposing on scattered regions a kind of functional organization which in most instances is not easily adaptable to American practice. The experience abroad, prior to the war, particularly in France*, Germany and Great Britain, however, points to the increasing number of professional and national discussions of the problem of the region.

In some instances, real progress has been made in lifting the perspective and philosophy above the 1900 level of thinking. In engineering, for example, both in water supply extension and in the co-ordination of rail and power facilities, new and practical steps have been taken to extend service to areas where it is needed. The test of need has been public necessity and desirability and not fiscal advantage. Both in Great Britain and in France a revaluation of the basis for making extensions into less dense and even rural areas has been made, with progress in actual extensions into such areas.

New and interesting problems of legal power have also been created in each of these efforts here and abroad. In this sphere, also, a change in viewpoint may become essential. The test for performing a service for the public should be whether or not the service is essential for public well-being, rather than whether a legal precedent, implied or actual, can prevent it.

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* For a report of activities in France, see: VIGNEROT. Report of the French Commission to the Congress of Liege, July 3–6, 1939. Regional Group for Public Supply of Potable Water. Tech. Sanit. Munic. (Fr.), **34:** 127, 1411 (Aug., Sept.-Oct., Nov.-Dec., 1939); *abstracted*—Jour. A.W.W.A., **32:** 173, 521 (1940). For Germany, see: TODT. Das Wasser. Deutsche Wasser-Wirtschaft (Ger.), **32:** 8 (Aug. 1938). For Britain, see: GORDON, LINCOLN. *The Public Corporation in Great Britain.* Oxford Univ. Press, Cambridge (1938).

Many other problems, of course, run parallel with the political and legal difficulties. Real formulas universally acceptable are still lacking for the partition of costs among the various functions necessary for the public, or the partition of costs among the beneficiaries of certain functions. It is not even clear whether any perfect syllogisms will ever be available. In the meantime, however, experimentation in this and other facilities must go forward to disclose both the opportunities and the experience with various approaches to the problem.

If we must go forward in the solution of major regional difficulties in this country, we shall be forced to do so largely upon an experimental basis, since even partially valid answers are not yet available. For example, before many years pass some administrative device must be made available to handle the increasingly complicated issues of water supply and sewerage facilities in the Ohio River Basin. An equally complicated, if not as pressing a situation confronts one on the Delaware River Basin. Problems of water supply and other utility servicing in the North Jersey area are matters of common knowledge and have been of a confused and pressing character for well over twenty years. Are the forces of engineering, law and politics in this country so inadequate as to be unable to provide some administrative answers to these issues? Perhaps one reason for the failure is the refusal to recognize and then to demand a change in perspective regarding the past techniques.

On the Ohio River, for example, are we at once to press toward six new and gigantic metropolitan districts for water supply, sewerage and general sanitary facilities, in the Pittsburgh; Youngstown-Niles-Warren; Steubenville-Wheeling; Portsmouth-Ashland-Ironton; Cincinnati; and Louisville metropolitan areas or shall we calmly and fatalistically sit down and await the millenium of slow evolution of a solution, as the areas in question become more and more confused and the damage greater and greater?

In arriving at solutions we are not unaware of the fact that these may cut across orthodox political boundaries of municipality, county and state, but unless they do we shall be no closer to solving the problem of servicing on a 1941 scale when people insist on living in such places and in such fashion as to ignore a 1918 or a 1898 boundary line. After all, this line, frequently imaginary and unknown to the man in the street, permanently acts as a "strait jacket" for the

engineer, the lawyer and the public official. In the words of W. S. Carpenter*:

"The successful readjustment of areas and services in local government depends upon a contradiction and its outcome. On the one hand, the traditional theory of democracy in the United States has emphasized the importance of keeping the conduct of the public services, which are the real ends of all local government, constantly under the scrutiny of the community. . . . On the other hand, it has become apparent that a multiplicity of governmental units [or none at all] tends to defeat efforts to obtain economy and efficiency in the conduct of public affairs."

An escape from this strait jacket and the dilemma of political philosophies represents largely the plea of this paper. An escape from them is possible, not by moving from an "old" to a "new" deal, but by a recognition of the fact that "novelty should impose no veto."

Perhaps no better closing words for this discussion can be chosen than those in an opinion given in 1896† by the late Mr. Justice Barrett of the Supreme Court of New York State:

"Growth and extension are as necessary in the domain of municipal action as in the domain of law. New conditions constantly arise, which confront the legislature with new problems. As the structure of society grows more complex, needs spring up which never existed before. These needs may be so general in their nature as to affect the whole country or the whole state, or they may be local, and confined to a single county or municipality. In any case, it is the duty of that legislative body which has the power and jurisdiction to apply the remedy. To hold that the legislature of this state, acting as the *parens patriae*, may employ for the relief or welfare of the inhabitants of the cities of the state only those methods and agencies which have proved adequate in the past, would be a narrow and dangerous interpretation to put upon the fundamental law. . . .

"Unless, therefore, we are to lay down a hard and fast rule limiting municipal action to what has already been done, and to nothing else, the mere fact that a rapid transit railroad in a city was never

* CARPENTER, WILLIAM SEAL. *Problems in Service Levels.* Princeton Univ. Press, Trenton (1940).

† Sun Printing Association *v.* New York; 40 N.Y.S., 8 App. Div. 230.

before planned or executed by a municipal corporation ought not to foreclose the question. The true test is that which requires that the work should be essentially public, and for the general good of all the inhabitants of the city. It must not be undertaken merely for gain or for private objects. Gain or loss may incidentally follow, but the purpose must be primarily to satisfy the need, or contribute to the convenience, of the people of the city at large. Within the sphere of action, novelty should impose no veto."

Discussion by *H. S. Morse*.* In discussing Mr. Wolman's paper I want to reinforce his comments concerning annexation as perhaps the best device for the development of metropolitan areas.

The expansion of cities has some of the characteristics of the search for new frontiers. Lower land values and lower taxes have been and still are the prime movers, but the automobile and electricity, together with private wells, make comfortable living possible beyond the city limits. This is a trend which might just as well be accepted gracefully. Nevertheless, an effort should be made to guide it.

These outlying areas are ever advancing. As the newly settled areas become more thickly populated, ordinary facilities will no longer serve. Septic tanks, at first sufficient, become dangerous as a means of sewage disposal and either sewerage or public water supply systems, or both, become necessary. Street lighting, refuse collection, pavements, fire protection, the usual sequence of improvements, bring increased taxable values and increased taxes. The new area, in turn, becomes old. Obviously, to obtain this development in an orderly fashion, gradual annexation to the mother city is the logical method.

In cities surrounded by small incorporated communities unwilling to give up their identities, metropolitan districts for various functions meet the situation. Also they are helpful in the development of suburban areas in the transition period prior to incorporation in the city. During recent years—perhaps the past two decades will cover the period—however, failure to use old-fashioned annexation has complicated the problem. The urge to be "bigger," if not better, seemed to pass and the pendulum swung to the extreme of indifference, if not opposition, to taking on the task of expanding the city. As Mr. Wolman indicates, the mother cities are loathe to add new

* Vice-President & Manager, Indianapolis Water Co., Indianapolis, Ind.

areas which are not self-supporting. Obviously if this policy, or rather lack of policy, was pursued along all lines of endeavor, progress in general would be halted. The remedy is education of public officials in the cities and the residents in the outlying areas, so that they may see the wisdom of a healthy, planned extension of the city limits through gradual annexation of these areas. Recognizing this fact, the Indianapolis Chamber of Commerce has a special committee working on this problem through legislation and education, and, in co-operation with the local Real Estate Board, is about to release a moving picture presenting the various aspects of the problem of city growth.

The settlers in these suburban areas must be helped to understand that water mains are not temporary structures but that they should be laid in streets with established grades, at a depth below possibility of freezing, and with sizes adequate for fire protection, although in these areas fire fighting service may not be available until they are annexed.

It might well be admitted that with the advent of all sorts of taxes and the imposition of super-taxes of the present day, the differences in property taxes, within and without city limits, are rapidly becoming relatively unimportant. Under an orderly program of expansion through annexation, the cities will eventually grow to the limits of the counties in which they are located. Then perhaps the next desirable step would be city-county consolidation, an economy in government which is seldom if ever mentioned in these hectic days.

Discussion by *J. S. Longwell.** Mr. Wolman has presented a very interesting and enlightening summary relative to the residential developments which have, in recent years, been taking place adjacent to most, if not all, of our larger cities. He has outlined the difficulties encountered in providing utility services in these areas, the drain upon the resources of the "old city" and the need for a new type of a public agency which will provide not only utility service but also all administrative and governmental functions such as fire protection, police, schools and similar items. The problem as outlined is nation-wide. One has but to visit any metropolitan area to see the pronounced tendency toward such a spreading-out process away from the original city limits. The reasons for this vary in

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different parts of the country but in general the movement is due to greater use of the automobile, better roads, the desire to have more space at low cost, the desire for greater freedom, and, finally, the feeling that taxes will be lower.

On the east side of San Francisco Bay nine cities, for the most part butting up against each other and, except in a few instances, with no physical demarcation between them, have organized themselves, under the laws of California, into a district, known as the East Bay Municipal Utility District, for the purpose of: (1) developing a new and larger source of water supply; and (2) purchasing a private water company supplying the area to permit the complete operation of a unified water system. [The organization and management of this District are discussed in detail by Mr. Longwell in a paper which appears on page 1897 of this issue of the JOURNAL.]

At about the same time as the District was first organized a substantial residential development began to take place in the unincorporated areas adjacent to the District cities. There followed then a long series of annexations (14 in all) to the original District, until at present the area of the District is 187 sq.mi. as compared with the original area, in 1928, of 94 sq.mi. The 1940 census showed the population of the District to be 519,000 of which 492,000 were located in the nine cities and 27,000 in the annexed areas. The District population in 1930 was 456,500.

With the formation of the District, each city still retained its own boundaries and functioned exactly as before, the District being superimposed upon the cities to permit handling the water supply for the entire area. As recently amended by the state legislature the Utility District Act, under which the East Bay Municipal Utility District was organized, provides a district with multiple powers.* From the Act, for instance, it will be noted that such a district may upon proper authorization by the electorate engage in the operation of many utilities. Thus far the development and distribution of a water supply has been the only activity of the East Bay District except for the operation of a hydroelectric power plant at the principal storage reservoir and the sale of its power to a power company.

Recent amendments to the Act also make it possible to establish special sewage disposal districts within the boundaries of the district to take care of the construction and operation of intercepting sewers

* See page 1898 for text of the provision.

and sewage disposal plants for any part of the district so established. This amendment to the Act was enacted to permit any combination of cities or annexed territory to handle their sewage disposal problems without in any way obligating the balance of the district. Under such an Act, utility service of all kinds can be made available to the area within the utility district in accordance with the demands of the residents thereof.

Within each city comprising the East Bay District, water service is provided to all residents at uniform rates. Other utility service is provided by private companies. All governmental functions are handled by each city independently. In the annexed areas, schools are provided by school districts which in some cases involve the areas included in two or more annexations. Fire districts have been organized covering most of the annexed areas. Street work and police protection are handled by the two counties under the direction of their boards of supervisors. Sanitary districts are being organized as required for installation and operation of sewerage systems.

Thus far there has been no inclination or desire on the part of the residents of the areas annexed to the District to annex to the various cities, nor has there been any serious demand on the part of the cities for such annexations. This problem may, however, develop as the annexed areas become more closely built up.

As stated by Mr. Wolman, the annexation of such areas to the "old city" is a process which can and should be used to a greater extent in the interest of an equitable distribution of the benefits provided by the "old city" to the residents of the adjacent areas. This, however, is a matter to be worked out in each community. Should this be done in the East Bay region, the District would still provide water service for the entire area, operating entirely independent of the other governmental agencies as at present.

Regardless of what may be done by these new areas adjacent to existing cities, whether they provide their governmental functions by annexation to the "old cities," or become a part of a new type of public agency along the lines suggested by Mr. Wolman, it is believed that the furnishing of utility services should be kept separate from the other governmental functions, so that they will stand on their own feet and be financially independent. This can be accomplished through an agency such as a utility district or similar independent authority. Such procedure, wherever used, has proved far superior to the old practice of operating the utilities as a part of the city government and has placed the utilities on a proper business basis.

Management Problems of a Municipal Utility District

By J. S. Longwell

THE California Municipal Utility District Act was adopted by the State Legislature in 1921, its provisions being drafted primarily to fit the requirements of such a district to serve the area located on the east shore of San Francisco Bay. Accordingly, the East Bay Municipal Utility District, organized in 1923, was the first community to take advantage of the new act. Originally, this district included the cities of Richmond, El Cerrito, Albany, Berkeley, Emeryville, Oakland, Piedmont, Alameda, and San Leandro, but, since its organization, six county water districts and a large area of adjacent unincorporated territory have been annexed until at present the district covers an area of nearly 200 sq.mi., with a population of about 540,000. The following discussion will refer specifically to this District.

In organizing the East Bay Municipal Utility District the primary purpose of those interested was to create a public corporation which could promote and finance the development of an adequate water supply to be brought in from a distant source. The private water company then supplying the area had nearly exhausted all local sources; and the financing of a new and adequate additional supply to provide for the future growth of the community was beyond the means of that organization. It was also contemplated that the new District should ultimately acquire the properties of the private company and tie in the new source with the existing system, for unified operation of all water supply facilities.

A paper presented on June 24, 1941, at the Toronto Convention by J. S. Longwell, Chief Engineer and General Manager, East Bay Municipal Utility District, Oakland, Calif.

It is of interest to note that the enabling act gives to districts formed under its provisions rather broad powers, providing among other things that:

> "Any Municipal Utility District incorporated as herein provided shall have power:
>
> "To acquire, construct, own, operate, control or use, within or without, or partly within or without, the district, works or parts of works for supplying the inhabitants of said district and municipalities therein, with light, water, power, heat, transportation, telephone service or other means of communication, or means for the disposition of garbage, sewage, or refuse matter; and to do all things necessary or convenient to the full exercise of the powers herein granted; also to purchase any of the commodities or services aforementioned from any other utility district, municipality, person, or private company and distribute the same."

All of the District's operations to date, however, have been confined to the development and distribution of a water supply and to the development of power as a secondary feature of its water supply, as described later.

Board of Directors and Officers

Management of the District is centered in a board of directors composed of five members, each elected at large and serving for four years. Elections are held every two years with two directors running for office at one election and three, two years later, thereby providing continuity in membership and preventing a complete change of the personnel at one time. In the eighteen years of its existence, there have been but few changes in personnel. The president has been a member for the full eighteen years and the previous president, who recently resigned because of ill-health, had been a member since 1924. The other members have served as follows: one for eight years; one for five years; one for two years; and one for two months. Service on the board is largely a matter of civic duty, since the salary as established in the Act amounts to but $10 per meeting, with pay for not more than two meetings per month. Thus, although four or five meetings are usually held each month, the maximum monthly salary is $20.

The District has been most fortunate in having had business and professional men of the highest standing to serve as directors, as a

result of which its affairs have been handled in a manner similar to that of any properly managed private institution.

The officers of the District consist of a general manager, an attorney, a secretary-treasurer and an accountant, who are appointed by and serve at the pleasure of the board. All other employees are under civil service. Each of the officers reports direct to the board and is assigned specific duties in the handling of District business. Officers attend the board meetings, usually held once each week, and discuss with the board all important matters pertaining to the four departments.

The General Manager is in charge of the Administrative Department. His duties include the handling of: (1) all general administrative matters; (2) civil service; (3) purchasing; (4) engineering; (5) operation and maintenance; (6) construction; (7) water and power sales; (8) land sales and leases; and (9) public relations and related matters.

The Attorney directs the Legal Department and takes care of: (1) all litigation; (2) preparation of contracts and leases; (3) the review of specifications and proposals calling for bids on materials and construction work; (4) approval of the investment of all funds; and (5) such other work as is delegated to him by the board.

The Secretary-Treasurer serves as secretary to the board and prepares its minutes and records. He is in charge of all District records, such as correspondence, contracts, deeds, leases and similar items. As treasurer he has under his direction: (1) the care and investment of all District funds; (2) the payment of all bond interest; and (3) the payment of the annual installments for retirement of bonds. He also serves as treasurer for the Retirement Board.

The Accounting Department, headed by the Accountant, supervises: (1) all general accounting matters; (2) preparation of cost data and reports; (3) compilation of budget reports; (4) the reading of consumers' water meters; and (5) the preparation and mailing of consumers' water bills.

Construction Undertaken

To finance the development of a new source of water supply and to provide for the construction of the necessary works, the people of the District, in 1924, voted bonds to the extent of $39,000,000. With the funds thus made available, the following construction was undertaken:

1. Pardee Dam was built on the Mokelumne River, about 100 mi. to the northeast of Oakland, creating a reservoir with a capacity of 68 billion gallons.

2. A power plant, with a capacity of 20,000 h.p., was constructed at the base of the dam to utilize both the water which must be released for supplying prior appropriators and surplus waters not at present required for domestic use in the District.

3. An aqueduct, 93 mi. in length and consisting of 81 mi. of steel pipe line, 9 mi. of tunnel and 3 mi. of concrete pipe, was installed to carry the water from Pardee reservoir to the District.

4. An additional terminal reservoir was built near the end of the aqueduct.

5. Two aqueduct pumping plants were provided.

6. A 15-mile length of pipe line was laid to distribute the new supply to other terminal reservoirs and various portions of the District.

The Mokelumne source is capable of producing a safe yield of 200 m.g.d., and the aqueduct diversion works, tunnels and concrete pipe have all been constructed with this capacity. The steel pipe line across the San Joaquin Valley, 81 mi. in length, has been built to carry 40 m.g.d. by gravity and 70 m.g.d. with pumping. Later, as community growth increases demands, it is planned to install a second and, ultimately, a third line to bring the aqueduct to full capacity.

Purchase of Private Water System

In 1927, with the Mokelumne system well along toward completion, the people of the District voted a second bond issue, this one for $26,000,000, for the purpose of purchasing the facilities of the private water company then supplying the area covered by the District. The purchase was made in December, 1928, and with the completion of the Mokelumne system in 1929, the two systems were consolidated. Since that date they have been operated as a unit by the District.

The distribution system as acquired consisted of some 40,000 acres of watershed lands; three terminal reservoirs with a total capacity of 31 billion gallons; three filter plants and numerous pumping plants, storage reservoirs, tanks and all other distribution facilities. Since that time two of the filter plants have been enlarged, two additional ones constructed and the entire distribution plant expanded to take care of the growth of the area.

Liabilities and Expenses

With the completion of the new Mokelumne system and the purchase of the distribution system, the bonded indebtedness of the District reached \$65,000,000. These bonds were of the serial type, carrying 5 per cent interest, with retirement payments to commence ten years after date of issue and to continue at 1/40 of the issues each year over the 40-year repayment period. Retirement payments on the \$39,000,000 bond issue commenced January 1, 1935, and on the \$26,000,000 issue, on January 1, 1938. The present total payments on both issues are \$1,625,000 due on January 1 of each year. All such payments have been made as they fell due and total indebtedness has by now been reduced to \$55,575,000.

Bond interest prior to January 1, 1935, was \$3,250,000 on the \$65,000,000 debt, payable January 1 and July 1 of each year. As retirement payments have been made, the interest charges have gradually decreased and in 1940–41 amount to \$2,820,000. Each year these payments decrease \$81,250 as the bonds are retired. Interest payments are met from the General Fund and an ample cash reserve or working capital has always been maintained to provide funds for meeting these charges promptly as they fall due. For the present fiscal year, bond retirement and interest payments total \$4,445,000.

Expenditures during 1940–41 for: operation; maintenance; capital investments on water mains, pumping plants, storage facilities and related items; taxes; insurance; contributions to the retirement system; and miscellaneous items will total about \$3,061,000. With the transfers to the Sinking Fund and interest on the bonded debt added to the above amount, the total of all expenditures is \$7,300,000. Deducting fixed charges, there remains \$2,771,000 representing salaries, materials, supplies, expenses and land purchases which is the amount to which most careful attention must be given by the management in its efforts to reduce construction costs, to eliminate items that may be deferred and to effect economies of operation.

Distribution System Rehabilitation and Extension

The distribution system on which the major portion of this amount is expended differs greatly from most in that a large part of the area served lies on the slope of the hills to the east of San Francisco Bay where it has been necessary to provide water for consumers at eleva-

tions ranging from sea-level to 1,500 ft. Water comes in from the aqueduct at about elevation 300, and all higher areas must be supplied by pumping to distribution reservoirs and tanks located as required throughout the hill area. To distribute this supply the District now operates 44 pumping plants, 23 distribution reservoirs and 45 storage tanks. Such a system requires many pressure zones to provide proper operating pressures for all consumers. Of these zones, 48 are served direct from reservoirs and tanks and 28 through batteries of pressure regulators.

The construction and operation of such a system is naturally much more expensive than for a community of more regular and uniform topography. Regardless of the elevation at which the consumer lives, he pays the same charge for water. This, of course, throws a heavy burden on the District and is a major consideration in the establishment of rate schedules.

In acquiring the 1,404 mi. of pipe in the distribution system of the private water company, the District obtained about 525 mi. of unprotected steel pipe less than 4 in. in diameter. In addition, many of the larger transmission and distribution lines were of steel without adequate exterior protection. Since a large part of the area served presents very bad soil conditions from an electrolysis standpoint, many of the steel lines have had to be replaced and a continuous program has been necessary to meet these requirements.

As a result, the District has, since December, 1928, replaced some 466 mi. of pipe, at the average rate of 39 mi. per year. In addition, during this same period, 319 mi. or 27 mi. per year of new extensions have been placed to provide water for territory annexed to the District, to care for new sub-divisions within the District and to take care of the rapid growth of the entire area.

Most of the pipe installed since 1928 has been laid entirely with District forces. In recent years, with the co-operation of W.P.A., many miles of old line, which otherwise could not have been attended to, have also been replaced. During the past two years the practice of contracting all installations where the labor cost was over $2,000 has been followed. In the fiscal year just closing, 69 mi. of pipe have been placed by District and W.P.A. forces and by contract.

At present there are approximately 151,000 active water services in the system, a gain of some 6,300 since July 1, 1940, and a total gain of 32,800 services since July 1, 1929. This increase over and

above the normal growth has, in the last few years, been largely due to the F.H.A. financing of new homes and also to the large home building program under way to take care of new employees at Army and Navy bases and at defense and related industries.

Sales Income and Other Revenue

The discussion, so far, has related largely to problems concerning expenditures for operation, betterment, and expansion of the system. Turning now to matters of income, the records show that during the present year the revenues received will be about as follows:

Water sales	$5,260,000
Power sales	381,000
Land and plant sales	233,000
Land rents	35,000
Advances by consumers for construction	132,000
Consumers guarantee deposits	72,000
Interest on bank balances	12,000
Miscellaneous	71,000
Total revenue	$6,196,000
Taxes	945,000
Total income	$7,141,000

The revenue from water sales which makes up the major portion of the District's income is approximately $150,000 less than it was in the previous year due to a rate reduction made in May, 1940. This reduction was anticipated in the water rate studies and in the preparation of the budget. All power generated at the District's plant is sold, at the plant, to a private power company. The sales total of $381,000 was about $23,000 less than provided for in the contract with the private power company, due to a shutdown necessitated by the damage to one unit by lighting. These losses, however, were fully covered by insurance and the corresponding income is listed under the item "Miscellaneous." It has been the District's policy to provide adequate insurance coverage on all such items and the advisability of such a practice was fully demonstrated in the case of this breakdown.

The item "Taxes," totaling $945,000, represents the amount of the income raised by an assessment against all property in the District and is made to obtain sufficient income to finance a part of the $39, 000,000 Mokelumne bond issue. In the twelve years that the system

has been owned and operated by the District the tax income has been reduced from $2,118,049 in 1929–30 to this amount, the rate being lowered from 50 cents per $100 assessed valuation, in 1929–30, to 20 cents in 1940–41, a saving to the taxpayers of $1,173,049 for the present year. It has always been the policy of the management to lower both water rates and tax rates as conditions permit, but the sound financial structure of the District is never endangered to accomplish this.

Water Rates and Fire Protection Charges

Water rates and charges constitute one of the major problems in any water department, company or district. It is a problem which must be studied continually in the light of changing conditions and new requirements. District charges for domestic, commercial and industrial service consist of a monthly meter standby charge, based on the size of the meter, and a charge of water used based on a sliding scale. These charges apply to all users of water and no exceptions of any kind are made. In this manner every water user within the District who consumes a like quantity pays the same price, regardless of the purpose for which the water is used. This practice has been in effect for many years and is believed to be sound in all respects, avoiding entirely the matter of special rates. For users who live outside the boundaries of the District a higher schedule applies, to offset the taxes being collected within the District.

Fire protection charges are made to each city within the District and to each fire district in the unincorporated areas. These charges are based on the additional investment of the District in filter plants, pumping plants, mains and other facilities to provide excess carrying capacity for furnishing adequate fire protection. The establishment of this charge is always more or less controversial, as a result of which it requires a great deal of study and investigation to present properly the facts showing justification for the charge. In the District, the charge is based on a modified inch-foot method which has been in effect since 1919, having been established originally by the Railroad Commission, the state regulatory body for the former private water company. Careful analyses show that the charge is eminently fair and that each city or fire district should bear its fair share of this excess cost. Decisions by the California courts have established the legality and propriety of such a charge.

Rate Reductions and Sales Promotion

Early in 1940 a very thorough study was made of the possibility of selling water at reduced rates to induce users of private wells to divert their business to the District. It was estimated that the use of private wells averaged about 6 m.g.d. and studies showed that by reducing the rates a large portion of this business would gradually be transferred to the District. Accordingly, in May 1940, a substantial reduction was made, affecting principally the larger users, but giving some saving to all, and representing a total annual saving of $360,000 to the consumers. Since the time of the rate change, a sales campaign has been conducted among the well users and, to date, 44 plants have shut down their wells completely, while many others have materially curtailed well use with the idea of abandoning all wells as trouble in operating them is experienced.

The program, so far, has resulted in an increase of about 1 m.g.d. in District sales and a corresponding decrease in well use. The campaign is being continued and next year should show an even greater increase. Results, thus far, have shown that the rate reductions are fully justified and that there is a possibility of exceeding estimated sales increases greatly. The success achieved has been based not only on price but on the high quality of the supply. With its principal source in the high Sierra Nevada Mountains, a filtered water, very low in hardness, is available to the consumers at all times. This is far better than the quality of the well supplies and is a strong point in influencing the well operators to change to District water.

Four rate reductions previous to the one discussed have been made during the past 10 years, and these together with the 1940 reduction have effected a total annual saving of $873,000 to the consumers.

Consumer Relations

Establishing good consumer relations in a utility district is much the same problem as in any other line of business. It is first essential that a high class product be made available. It is next necessary that proper service be furnished to all consumers in the way of adequate volume and pressure and that the consumers be treated courteously and promptly in all their dealings with the District, regardless of what they may be.

In an effort to follow this policy the District has established four business offices at convenient locations in different parts of the territory served, where consumers may make application for water service, obtain general information regarding such service, pay the monthly bills and arrange for having services turned on or off as required.

All services in the system are metered and all meters are read monthly. As the readings are made, bills are promptly issued, and mailed to the consumer within the next few days. In some cases bills are delivered by distributors. After receipt of bill the consumer may mail in his check, pay the bill at the four District offices, or pay at any of 49 branch banks and 9 agencies, located in stores and private offices in the outlying areas where no bank is available. In the event that bills are not paid within a reasonable period a collector calls at the home or place of business to obtain payment. Failure to pay within fifteen days renders the service subject to discontinuance.

The records of the business offices show that 4,790 new families have moved into the District during the past year and applied for water service. This does not, of course, include those making their homes in apartment houses or hotels. Shortly after a new family moves into a home, a representative of the District calls to inquire if the water service is satisfactory and, if not, to learn in what way it is deficient so that the necessary steps can be taken to correct the trouble. The representative also gives information concerning the source of water supply, the treatment of water and its high quality. He also supplies general information concerning rates and the operation of the system, and provides the consumer with a small pamphlet giving complete data regarding the supply.

Handling of Complaints

In addition to the new consumer contacts, similar calls are made from time to time among the older consumers. A representative takes a few blocks at a time in different parts of the system, so that a general cross-section can be obtained, and inquires of the consumer his or her opinion regarding water service. It has been found that these contacts not only create a more friendly relation between the District and the consumer, but also give the management some first-hand information as to what the consumer thinks of the service being rendered. Further it makes it possible to correct certain deficiencies and to eliminate potential complaints.

With 151,000 active services, numerous inquiries are received daily concerning practically all phases of furnishing a water supply. Many ask for information concerning source of supply, sprinkler systems, pressures, and quality of supply. Others may be complaints of poor pressure, dirty water, high pressure, taste, disturbing noises and related items. As these inquiries are received, a service inspector is dispatched to call on the consumer if the information cannot be given on the phone. At the time of the call the matter in question is carefully investigated and discussed with the consumer; every effort is made to be of assistance in making adjustments or in eliminating any deficiencies which may exist. Experience in handling inquiries and complaints over many years has convinced the management that prompt attention to all inquiries, no matter how trivial, and courteous treatment by the service inspector result not only in improved service, but in consumer confidence. For this reason it is essential that great care be used in selecting the personnel for service inspection work so that only those with the proper appearance, temperament and training will be assigned to this important work.

Publicity of District Activities

For many years the District management has believed that the general public should be advised concerning the properties which have been and are now being developed for providing an adequate water supply and also concerning the present operating methods as well as the financial status of the District. Accordingly, it has been the practice from time to time to send out in the monthly water bills a small information bulletin discussing different phases of the District's activities. These go to all water consumers and thus furnish an opportunity to reach every home in the District. Recently the pamphlet has been supplemented by stickers attached to the water bills encouraging the use of water for lawns and gardens.

Along with the information sent out with the bills, a program presenting facts concerning the District to service clubs, lodges, improvement clubs, churches, schools and other organizations has been followed. This was first handled by a District representative who presented a talk illustrated by lantern slides showing different structural features such as dams, reservoirs, filter plants, pumping plants and offices, together with some financial data. Later a silent movie was produced and shown to the various organizations. A

District representative gave a narration explaining the scenes as they were projected. The third step was the production of a sound-picture in black and white, entitled "The Story of Water," which described the development and distribution of the supply, stressing construction activities. Finally a sound picture in color, called "At the Turn of the Faucet," portraying the facilities that make the water available and dealing largely with actual operating methods was made available to the various groups to explain just how the water reaches the various consumers—domestic, commercial and industrial. This picture requires about 25 minutes to run and, in the ten months that it has been in use, it has been shown 267 times to about 19,100 people. A District representative always presents the picture and usually makes a short introductory talk. At the close of the picture, if time is available, he answers questions from the audience. It has been very well received and has been of great educational value in explaining to those who see it just how the District functions.

The District has also participated in a number of community enterprises, such as "Housing Expositions," "Flower Shows" and, during the summer of 1939 and 1940, had an exhibit at the Golden Gate International Exposition. For the latter, a model filter plant, showing the complete process, including aeration, coagulation, sedimentation and filtration, was built. Since then this model plant has been displayed in one of the schools and at one of the large filtration plants for the purpose of demonstrating to students and to those visiting the filter plant just how the water is handled.

Employee Relations

For carrying on its necessary engineering, construction, operation, maintenance and sales activities, the District has about 850 employees and, as is true for any organization of this size, the matter of personnel relations is a most important one. As previously stated, all employees except the officers appointed by the board are under civil service. Examinations are given under the direction of the General Manager and upon application from the head of a department or division, the personnel manager certifies the three highest from the eligibility list. After selection from among the three highest, appointment is made by the General Manager on recommendations of the department or division head. In giving examinations for various classifications they are for the most part promotional; that is, only District employees may participate. In filling the starting positions

and for special classifications where no qualified employees are available, however, open competitive examinations are given. This plan has worked very satisfactorily as it encourages employees to study and improve themselves so that they may advance to higher grades without competition from outside the District service.

Probably one of the most important features in any good personnel relations program is a well designed and operated "Retirement Plan." The District plan was placed in effect on October 1, 1937, after enactment by the State Legislature as an amendment to the Utility District Act. It is administered by a board of five members, of which three are appointed by the Board of Directors of the District and two elected by the employees. Payroll deductions are made monthly for each employee and these deductions are matched by a District contribution. The District also contributes all funds necessary to take care of prior service. Compulsory retirement takes place at the age of 70; voluntary retirement may occur at an earlier date, depending on the length of time the plan has been in effect.

The Attorney of the District serves as attorney for the Retirement Board; the District's Treasurer is also treasurer of the Retirement Board; the accounting work is taken care of by the Accountant of the District; personnel records are handled by the Personnel Manager, and a regular District employee serves as secretary. The Retirement Board members and its officers serve without compensation. The plan was worked out specifically to fit the District's requirements and has proved of great benefit to many employees. Its value is being more fully appreciated as more experience is gained.

Recognition for service with the District is given by the presentation of service pins. These are presented at five-year intervals, the first being awarded after five years of service. Presentation is made by the General Manager upon the anniversary of each employee. The pin is designed to be representative of the District's service, and a star is added for each additional five years.

Employees Association

The employees of the District operate an employees association, the dues for which are nominal. This association limits its activities to social and educational features. Some of its functions are an annual picnic, banquet, Christmas party, golf tournament and a fishing derby. It also sponsors athletic teams in an industrial athletic league. The association, in co-operation with the District

management, publishes a monthly magazine, named *Splashes*, containing articles relative to the District and its operations, news items regarding employees and photographs of work in progress and employees engaged in special activities. It is mailed to each employee every month and is looked forward to with a great deal of interest.

As a definite guide to employees in their various assignments and in their relations with other divisions and departments, a committee is now at work on the preparation of an employees' manual. This will contain a description of the District's activities, a statement of established policies regarding public relations and personnel relations, an explanation of the civil service and retirement systems, an outline of regulations concerning vacation and sick-leave privileges and many other related subjects. A copy of this will be presented to each employee; and it is the opinion of both the employees and the management that it will prove of great value in providing complete information relative to the District and in tending to iron out many troubles that might otherwise develop due to lack of definite knowledge as to established practices.

In conclusion, it should be pointed out that, in general, the problems of the East Bay Municipal Utility District do not differ materially from those of any department or company engaged in the furnishing of utility services. This paper has therefore been only a discussion of one particular organization and its system of operation and methods of handling particular problems, in an effort to serve best the needs of its consumers.

Joint Administration and Collection of Water and Sewer Accounts

Committee Report

FROM the outset of the work of the Committee on Joint Administration and Collection of Water and Sewer Accounts, it appeared that there existed a large amount of literature covering comprehensively the subject of sewer rental laws and the many types of sewer rental rate structures. Reference is made at the end of this report to several of these noteworthy publications. To those officials who are interested in the subject and wish to study forms of rate structures, the Committee suggests a review of these papers. The Committee acknowledges the use and study of these publications in the preparation of this report.

While in this report the terms "sewer rental" and "sewer service charge" may be used interchangeably, the Committee favors the expression "sewer service charge" as more descriptive of the service rendered. This should be considered when preparing material for educational or publicity purposes. Where the sewerage system is already in existence and perhaps paid for, the owner-user sometimes wonders if the "sewer rental" charge means that he is in fact paying twice for the system.

The sewer service or rental charge method has been fairly well worked out, but its application has raised other problems in connection with administration, billing and collection. These problems have, in an increasing number of cases, fallen upon the water department. They have been described very aptly as several series of problems rather than one particular question. On general policy and administration problems little has been written, and in all the data available there has been little to indicate the best practice or to guide the executive.

A committee report presented on June 25, 1941, at the Toronto Convention by Leonard N. Thompson, *Chairman*, General Superintendent and Engineer, Water Department, St. Paul, Minn.

With full realization that there exists a wide spread in local conditions, that laws, ordinances and local prejudices may be difficult to overcome, and that definite standards, applicable under all conditions, are not now possible, it is the hope of the Committee that its conclusions may here produce discussion from which will finally develop definite recommendations as to effectual, economical and workable administrative machinery and practices. These recommendations will then be available as a guide to those now struggling to emerge from their difficulties and to those water works superintendents who suddenly find themselves confronted with the task of collecting both sewer and water charges. Only by full discussion by all those who are interested, and by exchange of information among those having knowledge and experience, can a workable outline be established for others to follow.

Water superintendents have generally hesitated to endorse the joint administration of sewer and water works. Particularly have they been skeptical of the effects on the water department of assuring the collection of sewer service charges. At the start, the difficulties appear many, and it is true that the joint administration, billing and collection of water and sewer bills introduce certain problems, but experience is showing that, with proper rules and methods of procedure, these difficulties are not insurmountable, nor do they appear to place the water department in an unfavorable position.

New Problems in Sewerage System Administration

Sanitation and public water supply are both indispensable services in modern communities; although essentially complementary services, they have developed separately and in the great majority of cities are administered separately. The necessity for enlarged or improved sewage facilities has created new problems in financing, and, concurrently, means for more efficient administration. Not so long ago many cities were struggling under the burden of relief expenses and could not increase their bonded indebtedness. They feared to impose further increases in general property taxes. The revenue bond and service charge method of financing provided a practical solution for the many cities that were able to avail themselves of this method.

Today, with the inescapable necessity of increasing the national debt, state and municipal governments, accounting for approximately one-third of the total indebtedness, will be expected to keep expenses to a minimum. There probably will be some restraint on

new issues and in this situation the adaptability of the revenue bond method will prove its worth. Financing out of revenue from service charges—the revenue bond method—which does not add to the bonded indebtedness of the municipality, has gained great favor.

The Committee has attempted to determine the effectiveness of existing legislation permitting the construction of sewerage systems and sewage disposal plants, and of the authority for bond issues, general tax levies and sewer service charges. Twenty-seven states now appear to have adequate satisfactory legislation. Eight report either no legislation at all or unsatisfactory legislation. Two states report that special enabling acts are required, and two report difficulty in the sale of revenue bonds, suggesting need for careful review by the authorities creating the power to issue bonds. In but five of the 42 states reporting did there appear to be restrictions on the creation of metropolitan districts, although a complete analysis of the state laws would have to be made and a legal opinion obtained before a conclusion could be made regarding the actual situation in any state. The fact remains that a great deal of the legislation or amendatory legislation has been passed within the past ten years, indicating the growth in sentiment for water and sanitary districts. Some of this, however, has been emergency legislation and must be given careful study before amendments are offered. While adequate legislation appears to be available in 27 states, in only a few of the states have the provisions been used to any extent.

Replies from 30 water superintendents to a questionnaire on legislation, rules and policies, indicate that the water works profession is far from agreement on its ideas concerning either rates or methods of administration.

Desirability of Joint Administration

The establishment of special boards for the joint administration of the operation of a water department and a sewage disposal plant appears to the Committee to be largely a matter for local decision. Responsibility for maintenance, operation and construction of sewerage systems and disposal works may not, properly, be of concern to the water works administration, often being delegated to other departments. The *actual control* of plant operations of water and sewerage systems under one administrative head, however, would appear to have certain distinct advantages. The *administrative functions*, including the duties of billing and collection, present prob-

lems so similar in nature and may effect such economies that control under one administrative head seems most logical and advisable.

Since a water department has already set up the machinery and facilities for both billing and collection, separation of these functions is a duplication of effort and an expense neither justified nor effectually criticized because of the added burden placed on the water works superintendent. Since, generally, those who are beneficiaries of the sewage disposal plant or sewage system of the city are water consumers, the water department already has available the most reliable and complete consumer ledger system.

There is a wide variation in the officials on whom responsibility is placed. A recent survey of 91 cities showed 14 different classifications of officials in charge of sewer systems; 13 of the 91 were water superintendents, 11 joint superintendents of both water and sewer systems. Of 94 cities surveyed, 18 held water departments responsible for sewer rental collections. Thus, it seems that the responsibility for the administration of sewer rental charges is assigned in many ways, depending upon statutory provisions, governmental organization and the basis of rental. With the increased demand for improved sanitary conditions, it is becoming customary to make the water department the responsible agency through which a financial plan and subsequent administration can be worked out.

Problems of Joint Administration

A superintendent confronted with the problems of joint administration of the two services must, at the start, be concerned with certain definite problems:

1. The matter of legislation or statutory authority: It is highly desirable that such legislation: (1) clearly establish the administrative body and method of financing; (2) grant to such administrative body the power to adopt a rate schedule and necessary rules; (3) provide authority for the enforcement of all rules; and (4) make definite provision for the separation and disposition of all funds collected.

2. The determination of the amount of money to be raised by a sewer service charge after a policy has been established regarding the part of such charge that will be used to meet costs of operation, maintenance, betterments, extensions and debt service: When the sewer service charge is based on water consumption the superintendent can make a reasonable estimate of the probable returns. It is desirable that this sum be such that it will be reasonably constant over several

years, in order to avoid upsetting charges once they are established. For this purpose it is wise to design rates that will produce a slight surplus which may be used as a cushion against increased costs of sewage treatment or fluctuation in water consumption.

3. The method of raising the desired revenue.

4. The methods of billing and collection and control or accounting.

5. The adoption, by the administrative body, of local rules and ordinances governing the matter of collections, discontinuance of service, discounts or penalties, etc.

Sewer Rental Rate Structures

With the present high tax rates and, in many instances, tax limitations, every means is being sought to find new sources of revenue. The primary purpose of a sewer rental fund, however, should be to provide for the proper financing of the maintenance and operating costs of the sewage system and sewage treatment works. Practice has shown a wide variation in the extent to which such revenues are relied upon to meet capital, operating and maintenance costs, but the Committee feels that consideration should be given first to the combined method of financing, i.e., assessing the cost of construction against the property benefited and making a service charge for maintenance and operation, with authority to transfer any surplus income from time to time to amortization of the funded debt. Another variation of this method is to include in the service charge the cost of the treatment but not of the sewerage system itself. The revenue bond method for the entire cost is a special consideration and not susceptible to conclusive recommendations.

Installation of a sewer system and disposal plant is beneficial to all properties, even to vacant property, by enhancement of potential values, and, therefore, should be taxed for the costs of these improvements. The costs of maintenance and operation are attributable to and equitably chargeable to the users of the works. It is realized by the Committee that tax-exempt property will escape any payment of the capital costs, but legal opinion seems to indicate that sewer rental costs must be uniform and cannot be increased to the user of the system, located on tax-exempt property, when such increases are ostensibly for the purpose of collecting the equivalent of the tax item for construction.

About twenty different forms of sewer rental or sewer service charges are now existent, based upon uniform charges, the quantity

of water consumed, the number and type of plumbing fixtures, the number of persons served, the type of premises, the character of the sewage, or upon a combination of one or more of the above methods. The water superintendent, as administrator of such collections, should be vitally interested in and consulted in the establishment of any sewer rental rate structure. While the burden of responsibility for the rates should remain with the sewer division or the city administration, it is highly desirable that they be made with the advice and approval of the water works executive. In establishing the basis, the portion of the total cost which can properly be borne by the city as a whole, i.e., collected by taxation, and the balance to be collected as a reasonable charge against the users, in proportion to the individual benefits derived, must first be determined.

A discussion of the many methods or bases for sewer rentals is covered in the several publications previously referred to, but a study of the many methods and the apparent trend through experience prompts the Committee to favor a charge based on the metered water consumption, either as a percentage of the water bill, or directly on a consumption basis. Directly on a consumption basis, the billing may be at a uniform rate or a step rate. A flat rate is not fair to the small consumer. A rate based on fixtures is difficult to administer. The metered-water method is the closest approximation to the use of system that is practical of application. It is dependent upon complete metering, and modifications have to be taken into account for private supplies and such industries as use large quantities of water which are not discharged into the sewer system. When the water supply is not metered, a flat rate based on the size of the water service or connection, or a charge established as a percentage of the water bill, would produce an approximation of the foregoing method.

The cities of St. Paul, Minneapolis and Detroit have sewer rentals which are typical of the three methods based, directly or indirectly, on water consumption. All three methods have been operating very successfully.

Minneapolis bills for water at the uniform rate of $7\frac{1}{2}$ cents per 100 cu.ft. Sewer rental charges, which are also based on the metered water consumption, are on a sliding rate scale, as follows:

First	100,000 cu.ft.	@ 2.8¢	per 100 cu.ft.
Next	200,000 cu.ft.	@ 1.5¢	per 100 cu.ft.
All over	300,000 cu.ft.	@ 0.75¢	per 100 cu.ft.

The minimum bill rendered is 37 cents.

For one- and two-family homes the winter quarter water consumption is used as the basis for sewer rental charges throughout the year. The owner or occupant of this type of property is thus relieved of paying a sewer rental charge on water consumed for lawn sprinkling. Large consumers, of course, receive the benefit of the sliding scale. The annual revenue from sewer rentals is designed to care for operation and maintenance, 60 per cent of the fixed charges of the treatment plant and 30 per cent of the fixed charges on intercepting sewers. The balance of the costs are raised by a mill tax.

St. Paul uses a step rate for water consumption plus a fixed or service charge based on the size of the water meter. The sewer rental charges are only indirectly based on water consumption, being based upon the size of the water meter rather than on consumption directly, as follows:

Size of Meter	Annual Water Service or Demand Charge	Annual Sewer Rental Charges	Size of Meter	Annual Water Service or Demand Charge	Annual Sewer Rental Charges
$\frac{5}{8}$ in.	$3.00	$2.40	3 in.	$60.00	$75.00
$\frac{3}{4}$ in.	4.20	3.00	4 in.	120.00	180.00
1 in.	7.20	5.00	6 in.	240.00	360.00
$1\frac{1}{4}$ in.	10.20	9.00	8 in.	420.00	630.00
$1\frac{1}{2}$ in.	13.20	15.00	10 in.	600.00	900.00
2 in.	27.00	30.00	12 in.	—	1,350.00

The total collections for sewer rentals are used only for costs of maintenance and operation. This city reports that the method has worked well except that, since both the service charge for water and the sewer rental charges are based on the meter size, the department has received several hundred requests for a reduction in the size of the water meters. Reductions granted have, of course, reduced both water revenues and sewer rentals.

Detroit has a three-step water rate plus a service charge based on the size of the meter. The sewer rental rate of 11 cents per 1,000 cu.ft. of water consumed is added to each step of the water rates, and water consumed is billed at the one combined rate to include both water and sewage disposal, as follows:

	Water consumption charge	Sewage disposal rate per 1,000 cu.ft.	Total rate per 1,000 cu.ft.
First	10,000 cu.ft. per month 78¢ per 1,000 cu.ft.	11¢	89¢
Next	90,000 cu.ft. per month 60¢ per 1,000 cu.ft.	11¢	71¢
All over	100,000 cu.ft. per month 48¢ per 1,000 cu.ft.	11¢	59¢

The service charge is added to consumption charge and all shown as one item on the bill.

Exemption From Rentals

In certain localities the presence of one or more industries may so affect the strength or character of the sewage, due to the degree of pollution, that some account must be taken of it in the rate structure. This is particularly true when the cost of operating a sewage disposal plant is involved. Also, in certain industries, where a large amount of water is consumed, provision may be made to discharge the industrial waste so that little if any use is made of the sewage disposal system, or even the sanitary or storm systems themselves. While some cities take no account of this factor, it seems fair to reason that, when a large percentage of the water used is not returned to the sewers, some adjustment in the sewer service charge is proper and even necessary to meet statutory requirements. While the enabling act should provide the authority for such a change, it is the opinion of the Committee that the basic charges, based on water consumption, should still be continued, and such conditions treated as special cases, making equitable adjustments in the charges, and so preserving the simplicity of the general rate structure. The enabling act should give the administration or those invested with power to establish the rates, proper latitude to make certain uniform adjustments or exceptions to the rate structure.

Rates to Well-Supply Owners

Many cities are confronted with the problem of private sources of water supply, the water from which finds its way into the public sewer system. Authority for the billing of such accounts for the sewer service charge must be provided. There seems to be no reason why the same rates cannot be applied here as to users of the public water supply.

In St. Paul and Minneapolis there are 376 private wells, producing approximately 40 m.g.d. The two cities report favorably on the complete metering of the private supplies accomplished by ordinance, the sewer rental billing made in Minneapolis being on the water pumped from the private wells, and in St. Paul on the size of the meter as set on the well.

In these cities, where the private supplies have been metered for about eighteen months, it is reported that there has been no par-

ticular criticism. In both cities each case was individually investigated and the owner advised regarding type and size of meter. Perhaps the greatest difficulty experienced was the stoppage of meters due to sand pumped from the wells. In St. Paul, where the charges are based on the size of the well meter, the billing is continued until a well is reported out of service and sealed. The installations of small wells for air-conditioning, which are not used during the winter months, are billed throughout the year.

Ordinances should provide for the registration with the billing agency of all old and new sources of private water supplies. These meters should be read and treated as any other account. Since the department has no method of discontinuing such private supplies for non-payment, provision should be made to place delinquencies on the tax rolls or to file them as a lien upon the property.

Rates to Suburban Developments

The trend toward suburban development in many cities has become a real problem. Those who move outside the corporate limits of the city for various reasons, in some cases to avoid city taxation, demand the same utility services they enjoyed in the city. When tax funds have been used to construct and maintain a sewerage system and/or a sewage disposal plant it seems unfair that such facilities should be placed at the disposal of non-residents at less than actual costs. When metropolitan districts are established to furnish utility service to such areas, it is highly desirable that sewer rental charges be increased to represent at least the equivalent amount paid by those taxpayers who are or have paid for the construction of the utilities services. The Committee feels that there is every justification for the creation of metropolitan utility districts, but where those consumers of the service are beyond the tax jurisdiction of the municipality, the payment for such service should represent at least the equivalent of the sum total payments made directly or indirectly by the consumer for like service inside the city, including all costs of amortization, interest, depreciation, maintenance and service.

Joint Billing Practices

The difficulties encountered in the collection of sewer service charges are not very great once a sound and workable method is adopted. Sewer bills or sewer service charges may be made separately and entirely independently of the water bill, separately and

attached to the water bill, included in the amount of the water bill, or shown as a separate item on the water bill.

There is a natural antipathy among water works men toward confusing the water bill with charges which are primarily of no concern to the water department. Placing additional charges on a water bill, it is felt, will conjure up in the mind of the consumer the idea of an increased water bill. For this reason the practice of making separate bills has often been employed. The Committee is of the opinion that the additional expense involved in issuing separate bills is not justified, that experience is proving that a water bill, carefully prepared and explanatory, will neither confuse the consumer nor bring undue criticism upon the water department. It is reported that during the initial stages many inquiries are received but that once the additional charge is understood, the complaints are few.

Simplicity in rate structure and in billing is highly desirable. One of the strongest arguments in favor of a rate based on water consumption is the ease with which the charge may be included with or on the water bill. The bill should be clear and should properly indicate each charge. A statement of the rate schedule is highly advisable. Proper publicity prior to the initiation of the combined method of billing and proper explanation have been found to work successfully and to overcome the fears of the superintendent. Reports indicate little, if any, increased delinquency in the payment of water bills. A printed notice on all water bills to the effect that the water department is acting only as the collection agency for sewer rental charges and that the funds are maintained separately has proved helpful in a number of cases.

Practically all public utility types of billing machines can be so constructed as to indicate the water charge and the sewer rental charges separately, and to tabulate or accumulate the two accounts separately for proper accounting purposes. This process is available even to the extent of duplicating or repeat-printing the amounts on the bill proper and on the cashier's stub. Much clerical and consumer's time may be saved and a clear record kept if all collections made are credited on the one ledger card under proper headings. Accounting control and trial balances are simplified. Separate accounting of each fund is highly desirable, and since the water department is acting only as the collection agency, the funds collected for sewer rental purposes should be credited directly to such an account and turned over to the proper authorities for disposition and dis-

bursement. Colored ledger cards for carrying the accounts of private supplies are desirable and helpful in distinguishing the type of supply easily and quickly, without interference with the financial control system.

Effect on Delinquency

Some provision must be formulated in the case of delinquents. Simplicity indicates that the same discount rate or penalty should be applied to sewer and water accounts.

The water department should have the right to instigate all rules governing the method of collection, time or period of billing, to correspond with the regular water billing periods, the rules for collection of delinquent accounts, turn-off for non-payment, etc. Since it is not practicable to shut off a sewer connection, the most logical and practicable method of forcing payment of sewer rental charges is to demand that they be paid with the water bill, with right to deny service of both. While on the face of it, it does not seem fair to a water department to be required to deny service to a water consumer because he refuses to pay a sewer rental charge, here again experience shows that the percentage of delinquencies is very small, varying usually from zero to 10 per cent in 37 cities, with one city reporting 20 per cent and two as high as 30 per cent in the depression period. There is no reason to believe that the sewer rental charge on a water bill has increased delinquency.

Billing Procedure in Special Cases

In practice it will be found that numerous accounts are not connected to the sewer system, and, therefore, are not subject to the sewer service charges. In one city a charge is made where the sewer is available, irrespective of whether actual connection is made or not. In another, no charge is made until actual connection is made. In initiating the sewer rental charges in the latter city, the charge was, initially, placed on all ledger accounts and billed, until complaints and investigation proved the error.

When charges are based on the water consumed and allowance made for lawn sprinkling, it is the usual practice to establish, by a review of the reading sheets, the normal or average consumption for one billing period at each premises as indicated in the off-sprinkling or winter months and to indicate the amount so arrived at on the reading sheets and ledger cards as the average domestic consumption. The

sewer service charge is then applied to this same consumption at each billing period. Established percentages of the water charge or fixed charges, when these methods are used, and any other information necessary to billing should be entered on both reading sheets and ledgers. The water superintendent should see to it that his department is reimbursed for all expenses incurred in carrying this added service. These costs may include additional billing equipment, the cost of changing over some equipment to meet new demands, the cost of new ledgers, a fair and proportional share of the postage, clerical and miscellaneous expenses.

The water superintendent should have the complete co-operation of the public works department, sewer department or whatever agency controls the installation of new sewer connections, in order that records may be completely and accurately up to date. Insofar as possible each department should be self-sustaining, free from any political interference and in full control of the revenue received, subject only to the limitation that they be expended for water works and sewerage services and for no other purpose.

It has been suggested in committee that a further study of this subject might now very well be carried on through a joint committee of the American Water Works Association, the American Society of Civil Engineers and the American Public Works Association, since up to this time each society has carried on an independent study.

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Discussion by *John A. Hickey*.* The city government of Cleveland is the Department of Public Utilities, in which there are three divisions: (1) Water and Heat; (2) Municipal Light and Power; and (3) Sewage Disposal. The Department of Public Service was in charge of the construction, operation and maintenance of the sewer system and some of the earlier sewage disposal plants prior to their enlargement. In 1923, the operation of the disposal plants then constructed was placed in charge of a sanitary engineer in the Division of Water and Heat of the Department of Public Utilities. These plants were operated out of water works funds until a court decision in 1934 declared the use of such funds illegal. A year or two prior to this date, a program of enlargement of the existing disposal plants was begun, and bonds which were obligations of the City were issued. At the same time, the actual construction of the enlarged plants was placed directly in charge of the Director of Public Utilities, in conjunction with the City Consulting Engineer. Out of an expenditure of some $14,000,000, approximately $3,000,000 was furnished by P.W.A.

At the time the use of water works funds for the operation and maintenance of the sewage disposal plants was declared illegal, revenue for this purpose was obtained from the general tax fund. With the beginning of the operation of the enlarged plants, however, new sources of revenue were necessary, and under Section 3891-1 of the Ohio General Code, an ordinance was passed to provide the necessary revenue from sewer rental charges. Since it required about $1,000,000 a year to operate and maintain the new disposal plants, a charge sufficient to meet these costs was incorporated in an ordinance (Ord. No. 558-A-38) in which a charge of 40 per cent of the water bill was made to each user of the sewer system. The fixed charges of about an equal amount, i.e., $1,000,000, were derived from general taxation.

Although the city engineers had made estimates of the cost of the operation of the disposal plants and finally submitted the problem to a special board of consulting engineers which had recommended a charge on the basis of the water used, opposition to this form of raising the revenue arose and has continued to the present time. The first ordinance was in effect on the 40 per cent of the water bill rate for fifteen months (from July 17, 1938 to October 18, 1939). On October 18, 1939, there went into effect a reduction of this rate from 40 to 25 per cent of the water bill, and this rate was in force for a period of three months. A previous ordinance (Ord. No. 2287-38) became

* Director of Public Utilities, Cleveland, Ohio.

effective on January 17, 1940, repealing the first ordinance and leaving the Division of Sewage Disposal without any funds other than certain revenue that was obtained from old contracts with adjoining municipalities and county sanitary sewer districts, and a $240,000 appropriation from the general fund. Agitation still continued, however, and in spite of the administration's advocacy of the method of sewer rental for obtaining the necessary revenue, no new ordinance for raising money was enacted until March 1, 1941 (Ord. No. 2077-40). This ordinance is now in effect and the charge is 18 cents per 1,000 cu.ft. of water passing to the city sewers. It remains in effect until December 31, 1941, when the whole question must be reopened. Although the electorate had twice expressed an opinion in regard to the method of raising this revenue, i.e., by the sewer rental method, and even in light of the special board of engineers which had endorsed the earlier recommendations of the department's engineers, opposition to the method is still extremely aggressive.

Consumer Demands for Exemptions

In Cleveland, the duties of billing and collecting sewerage charges is the function of the Division of Water and Heat. There has been no particular difficulty about arranging for the transfer of the work from the Division of Sewage Disposal to the Division of Water, since the latter has all the necessary data on which to base the charge. Bills are rendered quarterly and the sewerage service charge is placed upon the bill, together with the water charge, large consumers being billed monthly. The principal difficulty has been the question of exemptions from the sewerage service charge. It is rather astonishing the number of involved questions which can arise from the interpretation of an ordinance which seemingly states clearly the basis for the charge:

"*Section 3.* That for the purposes stated in Sections 1 and 7 hereof, there is hereby charged, levied and assessed upon each lot or parcel of land in the City of Cleveland, on which a structure has been or may be erected having connection with the sewerage system of Cleveland or otherwise discharging sewage, industrial wastes, water or other liquids, either directly or indirectly into the City sewerage system, a sewerage service charge based upon the quantity of water used thereon or therein as the same is measured by a water meter or meters there in use, which charge shall be eighteen (18¢) cents per 1,000 cubic feet of water so measured, regardless of whether the water passing into the

sewer is derived from a source other than the city water supply or if such water or any part thereof is furnished to premises without charge. If the whole or any part of the water on which a sewerage service charge is based is shown by an approved measuring device not to have passed into the city's sewers, then the charge shall be based upon the actual amount of water which actually passes into the city sewers. For special cases which are not clearly provided for in this ordinance, rates may be established by council upon the recommendation of the Director of Public Utilities."

It will be noted that the charge is based on the use of the sewers and that the ordinance distinctly enumerates "industrial wastes, water or other liquids, either directly or indirectly [passing] into the City sewerage system." Such questions as that of whether a storm sewer, into which, presumably, no sewage is allowed to pass, is a part of the sewerage system or not, arise frequently, as do such others as:

1. What is the definition of a "sewerage system?"

2. Are disposal plants a part of a "sewerage system," or only the laterals, main and trunk sewers included, together with the interceptors?

3. If revenue is raised by rental charges and applied *only to* the operation and maintenance of disposal plants, can those who contribute sewage to sewers which are not connected to the disposal plants be assessed a charge?

Problems arising from the separation of water converted into sewage and that which enters a salable product are frequently difficult to solve. For example, ice manufactured and sold off the premises could not be charged for, but ice made and used on the premises could be. How best to measure the water entering the manufacture of soft drinks, beer, distilled liquors, steam boilers, where condensed steam is returned to the boilers, steam heating systems serving considerable areas, and where the condensed steam is returned through a meter to the sewers, is still another problem.

During a period of eighteen months, during fifteen of which the users of the service were billed at the rate of 40 per cent of the water bill and three months at the rate of 25 per cent of the water bill, there were placed on the department's books, the sum of $1,756,152. Of this amount, $343,226 became delinquent. These unpaid charges were certified to the County Auditor and placed as a lien upon the real estate served. This is in accordance with the state law on

sewer rental charges. It is interesting to note that there were 19,615 delinquent accounts and they represent over 16 per cent of the 121,971 accounts. The delinquent accounts totaled almost 19.5 per cent of the total billed accounts. It is of further interest to note that an inspection of the amounts due on delinquent accounts showed that 75 per cent of them were for an amount less than $10.

Discussion by *Hal F. Smith*.* This report is a timely and valuable contribution to the literature of the field. It points out the general procedures that are fairly well established and also the many details in which no semblance of uniformity has been attained. In a very practical manner the report breaks up the general subject into its component parts and presents each part for discussion and consideration.

There is no reason to expect that complete uniformity of procedure will be attained, nor is there any reason to believe that such is essential or even desirable. The report does not offer any complete, ready-made procedure, but it does present the subject in such a manner as to be of material assistance to the man who is interested in selecting or developing the procedures that best meet his particular needs. Many of the points discussed in the report are controversial, but rather than discuss further the relative merits of the several procedures, the writer will outline briefly the procedure used by the Detroit Department of Water Supply, the reasons for its selection and the results obtained.

As a starting point, it seems necessary to explain that the Detroit Department of Water Supply is headed by a four-man commission, appointed by the Mayor. Its only income is that derived from the sale of water and, on the other hand, it is prohibited by the city charter from diverting any of its resources to any other use.

The sewage system was constructed and is maintained by the Department of Public Works from general tax revenues. The sewage disposal system, consisting of treatment plant and interceptors, was built by the Department of Public Works and financed from tax revenues, from the sale of revenue bonds, and P.W.A. grants.

For reasons of necessity and expediency it was decided to raise the funds necessary to operate and maintain the sewage disposal system and to retire the revenue bonds and meet their interest charges by making a utility charge for service rendered. Decision was made on the following points:

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1. The operation of the sewage disposal system was transferred from the Department of Public Works to the Department of Water Supply as an economy measure, since it was evident that the operation of the sewage disposal plant more closely paralleled that of the Water Department, and because the Water Department already had the equipment, personnel and experience needed in the billing and collecting of utility charges.

2. It was then decided to base the sewage disposal charge on metered water consumption because it appeared that water consumption was the most satisfactory and equitable measure of the service rendered by the sewage disposal system.

3. Detroit adopted a single-step rate for the sewage disposal charge for the reason that the entire charge is for treatment and disposal of sewage that is picked up by the interceptors, so that the cost of treating and disposing of any given unit of sewage is identical to the cost of treating and disposing of any other unit, regardless of whether the unit was contributed by one large contributor or many small ones.

4. Consideration was then given to whether the charge should be billed on a separate bill form, as a separate item on the water bill, or included in the water bill. For reasons of economy it was decided to include the sewage disposal charge in the water bill and to make a clear explanation of this combined billing on the bill form. This choice of procedure has made it possible for the department to take over the job of billing, collecting and accounting for sewage disposal charges with no additional expense. In general, customers have understood the additional charge for sewage disposal and the combined form of billing, with the result that there has been no appreciable effect on customer relations. It did, however, necessitate the working out of a plan that could be depended upon to effect a complete and accurate segregation of water and sewage disposal receipts. The plan adopted cannot be explained briefly, but it is given in detail in the paper referred to in the Report (3).

5. Next to be considered was the question of who should be held responsible for sewage disposal charges. Inasmuch as water charges in Detroit are a lien against the property served, the sewage disposal ordinance was drawn to make the sewage disposal charge also a lien and enforceable in exactly the same manner as is the lien for the water charge. This provision is, and must be, supported by state law.

6. The next question was that of determining a satisfactory means of forcing payment of sewage disposal charges. While the right of lien is a formidable weapon for use against delinquent customers, it is

a most cumbersome and costly one because of the expense of foreclosure, which usually exceeds, to a considerable extent, the ordinary sewage disposal or water charge. Its principal value lies in its ability to fix responsibility and depends largely upon some other agency actually to force collection. The perfect combination is the right of lien to establish liability and the right to discontinue the sewer service and/or water service to the property for non-payment of the sewage disposal charge. The Detroit ordinance was drawn to provide for all of these measures.

7. Detroit makes a charge for sewage disposal service, to all properties that are connected to the system, on the basis of water consumed, making no adjustment or allowance of any kind for water which is not eventually discharged into the sewer. No adjustment has been made for the reason that no satisfactory method of adjusting has yet been determined. The department, in co-operation with some of the larger industries in the city, is now working on this problem. Of particular interest in this connection is the fact that during the sixteen months that the sewage disposal charge has been effective, less than 30 requests for adjustment of the sewage disposal charge, on the grounds that all or part of their water consumption did not reach the sewer, have been received. The requests for adjustment that were received were, in general, from large industrial plants.

8. An ordinance was passed by the Common Council requiring users of private wells, or any other private sources of water supply, to meter or measure such supply in a manner satisfactory to the Department of Water Supply, as a means of determining the proper charge for sewage disposal service. The regular sewage disposal charge is applied to water consumed from private sources.

9. It has been the experience of Detroit that the inclusion of the sewage disposal charge in the water bill has not had any appreciable effect on collections.

Perhaps the most important contribution that could be made at this time is to state that, after all the dire predictions of the difficulties that would result from billing and collecting sewage disposal charges, the entire Department personnel has been somewhat amazed to find how simple the operation turned out to be.

Iron Removal in Western Pennsylvania

By L. S. Morgan and C. H. Young

THE twenty counties which are considered to comprise Western Pennsylvania have a total population of over 3,500,000. Nearly 400 public water supply systems in these counties serve water to approximately 2,750,000 people. Of these supply systems almost 60 per cent, serving more than 475,000 people, derive their supply from ground water, principally through wells. In the northwestern counties about 70 per cent of the total public water systems secure their supply from ground water, but in southwestern Pennsylvania the extensive mining operations have depleted ground waters in some areas so that only about 50 per cent of the total public water systems employ ground water as their source of supply.

Generally, ground water serves as the source of supply for the smaller public water systems. These ground waters have varying chemical characteristics, ranging from practically zero hardness with low mineral content to serious hardness with objectionable amounts of minerals. Many of the ground waters contain iron or iron and manganese in objectionable amounts. Likewise, certain surface waters contain iron or iron and manganese, the source of which is usually either mine drainage or spent acid wastes that are discharged to the streams. All surface supplies except some of the impounded upland supplies are filtered, so that treatment facilities are available for removing iron or iron and manganese during the purification.

Usually iron bearing waters as secured from the ground contain little or no dissolved oxygen and considerable amounts of carbon dioxide. The carbon dioxide stabilizes the iron and holds it in solution in the ferrous state as ferrous bicarbonate ($FeCO_3H_2CO_3$). Occasionally in the coal mining regions ferrous sulfate ($FeSO_4$) is encountered in well waters.

A paper presented on August 8, 1941, at the Western Pennsylvania Section Meeting, Erie, Pa., by L. S. Morgan and C. H. Young, District Engineers, Pennsylvania Department of Health, Greensburg and Meadville, Pa.

When the iron exists in the ferrous state, as carbonate, it can be removed by various treatment processes, including: (1) aeration followed by filtration through media such as sand or birm; (2) aeration, sedimentation and filtration; (3) treatment with lime, soda ash or lime-soda softening, followed by sedimentation and filtration; (4) base-exchange with sodium zeolite without aeration; and (5) oxidation and filtration through special media, such as manganese zeolite. These methods involve two basic methods for iron removal, i.e., oxidation and filtration, and chemical treatment and filtration.

When the iron exists in the sulfate form, an alkali, such as lime or lime and soda ash, is required to convert it to insoluble hydrate, which is removed by subsequent settling and filtration.

Iron Removal Facilities

The installation of iron removal facilities has not kept pace with the other water purification improvements either because the supplies affected are usually those of small systems, where finances are limited, or because the lack of appreciation or understanding, on the part of the consumers, prevents improving the quality of the ground water supply.

A public water supply containing iron in an amount exceeding 0.3 to 0.6 p.p.m., depending upon the character of the water, is usually objectionable in that it produces colored and turbid water, deposits in the mains, staining of plumbing fixtures and staining of clothes during washing, and in that it is objectionable in the preparation of foods. In some municipalities the iron content of the public supply has resulted in the continued use of cisterns and shallow wells as sources of water which is not objectionable for washing and other domestic purposes. A number of treatment plants for the removal of iron have been installed on Western Pennsylvania water supplies. These plants embody different methods of treatment for ferrous iron waters, such as sodium and manganese zeolites, birm, contact aeration and filtration, lime treatment and filtration and lime or lime-soda softening. The data given in Tables 1–6 have been assembled to permit reviewing the design and operation of the different treatment methods.

The chemical results given under the heading "Raw Water Quality" have been taken from the operation reports of those plants equipped with laboratory facilities, and from state health department chemical

records in the case of those plants not provided with complete laboratory facilities. Dissolved oxygen, carbon dioxide and pH determinations have been made in the field. It will be noted in the raw water determinations, under "Operation Results," that colors and turbidities are indicated for most samples. All of the water samples were clear at the time the samples were collected, but oxidation of iron occurred during the transportation period to the laboratory, causing the color and turbidity to appear as shown in the results. The samples indicated as tap have been collected from the distribution system at one of the more distant points from the plant.

Sodium Zeolite Plants

Sodium zeolite has the property of removing ferrous iron and manganese from water in the same manner as calcium and magnesium are removed in water softening. This property has added much to the value of the material for water purification purposes in Western Pennsylvania, because many of the ground waters contain iron or manganese, or both, in addition to being hard. Sodium zeolite will continue to remove ferrous iron and manganese, if not in too large amounts, for a period of time even after it has become exhausted. This property is indicated in the chemical results of both the Coraopolis and Edgeworth filtered water (Table 1), where the zeolite filters were overrun at the time the samples were collected.

If filtration is continued through the so-called "twilight zone" beyond the softening point, iron and manganese will pass through these units. Ambridge (Table 1) experienced deposition of manganese in the underdrain system during the early period of operation of the plant by operating the zeolite filters beyond the softening cycle. At times of high manganese in the raw water, it was found that manganese began to appear in the effluent shortly following the end of the softening cycle. The raw water of the three plants selected usually contains small amounts of iron; but the manganese contents vary from a small quantity at Coraopolis to a large one at Ambridge. Operation results of these plants at the end of five or six years' use show that there has been no material reduction in the exchange capacity of the zeolite. The zeolite at the Ambridge plant has been coated a dark black since the beginning of the second year of operation. The zeolite at the Coraopolis and Edgeworth plants is also stained black, but the zeolite grains have not increased in size. Ac-

TABLE 1

Design and Operation of Sodium Zeolite Plants

	AMBRIDGE	CORAOPOLIS	EDGEWORTH
Raw Water Quality			
pH	6.8 – 7.2	7.3– 7.6	7.3– 7.7
Alkalinity, *p.p.m.*	69. –100.	70. –100.	85. –100.
Hardness, *p.p.m.*	120. –350.	140. –260.	130. –180.
CO_2, *p.p.m.*	15. – 33.	20. – 25.	10. – 15.
Fe, *p.p.m.*	0.60– 1.2	0.3– 0.60	0.5– 0.6
Mn, *p.p.m.*	3.8 – 8.0	0.7– 1.2	1.1– 2.6
Temperature, *deg. F.*	44. – 65.		
Design and Operation Data			
Source of supply	Wells	Wells	Wells
Treatment units	Gravity zeolite filters	Pressure zeolite, filtered water aerated and alkalinized	Gravity zeolite filters
Zeolite filter area, *sq.ft.*	* 576	250	300
Water treated, *g.p.m.*	1,000	850	630

Operation Results

	Raw	Filter	Tap*	Raw	Filter	Tap†	Raw	Filter	Tap†
Color, *p.p.m.*	5.	5.	5.	5.	5.	0.	10.	5.	0.
Turbidity, *p.p.m.*	5.	5.	5.	5.	5.	0.	10.	5.	0.
Total residual, *p.p.m.*	550.	515.	525.	325.	330.	325.	265.	285.	265.
pH	7.0	7.0	7.5	7.2	7.2	7.6	7.6	8.0	8.0
Chlorides, *p.p.m.*	32.	32.	54.	28.	28.	28.	15.	32.	18.
Oxygen consumed, *p.p.m.*	0.5	0.8	0.8	0.6	0.6	0.6	1.0	1.0	1.0
Total hardness, *p.p.m.*	350.	6.	76.	230.	28.	76.	180.	40.	90.
Alkalinity, *p.p.m.*	100.	90.	80.	100.	105.	100.	95.	100.	100.
CO_2, *p.p.m.*	33.	30.	12.	20.	8.	2.	10.	—	12.
Dissolved oxygen, *p.p.m.*	0.	—	5.6	0.	0.3	6.0	0.	—	3.9
Total iron, *p.p.m.*	0.8	0.	0.	0.3	0.	0.	0.6	0.2	0.2
Mn, *p.p.m.*	6.0	0.	0.	0.7	0.	0.05	1.5	0.05	0.
Temperature, *deg. F.*	62.	—	—	60.	—	—	59.	—	—

* Mixture lime treated and zeolite softened water.

† Mixture zeolite softened water and hard water with Fe and Mn removed.

cumulation of manganese on the zeolite grains has not increased with continued use of the plants. The iron and manganese removed by the zeolite are eliminated during the regeneration of the media with sodium chloride.

Birm Plants

The three plants using birm for iron removal (Table 2) have been in operation for about four years. Birm is a special filter material that is produced to remove iron from water catalytically and does not require regeneration; but it will not soften water. Birm, too, has certain other limitations, in that the water must first be aerated or at least must contain dissolved oxygen sufficient to combine with the iron; it must be free of such reducing compounds as hydrogen sulfide, and the water must be alkaline.

The three plants discussed have not been free of difficulties. The well water is aerated at all three plants. Aerators have been provided for adding dissolved oxygen and removing carbon dioxide and some hydrogen sulfide which is present in the well water at these plants. Aeration increases the dissolved oxygen content of the water at the three plants from zero or nearly zero to about 7.5 p.p.m., at the same time reducing the carbon dioxide about 60 per cent. The coke tray aerators serve as contact aerators and effect some reduction in the iron content of the well water as the coke and the receiving pans under the aerators are flushed to the sewers regularly.

The birm at two of these installations is heavily coated with iron and new birm has been required for the filters, or it has been necessary to remove the birm for cleaning with water and potassium permanganate. The original effective size of the birm media installed at the Oakdale plant was 0.28 mm. After several years operation, excessive losses of head were experienced in the pressure filter and the birm was removed and washed. The washed birm as replaced had an effective size of 0.63 mm. The material was then noticeably coated and some fine material was lost in the washing process. Aeration and birm filtration have largely eliminated complaints of "red water," although there is an iron pick-up of 0.3 p.p.m. in the system.

With waters of high iron content, this material requires substantial wash water volumes. The Oakdale chemical results indicate a complete removal of iron, although failure to remove the high manganese content raises a question as to the value of this method of

TABLE 2

Design and Operation of Birm Plants

	OAKDALE	SLIGO	SHIPPENVILLE
Raw Water Quality			
pH	7.0– 7.5	6.8– 7.4	5.8– 6.4
Alkalinity, *p.p.m.*	170. –200.	135. –205.	20. – 76.
Hardness, *p.p.m.*	300. –500.	64. –120.	44. – 80.
CO_2, *p.p.m.*	— – 55.*	20. – 33.	45. –109.
Fe, *p.p.m.*	2.0– 5.0	0.4– 8.0	6.0– 20.
Mn, *p.p.m.*	1.2– 3.0	0. – 0.30	0. – 0.6
Design and Operation Data			
Source of supply	Wells	Wells	Wells
Treatment	Coke tray aeration, pressure birm filter	Coke tray aeration, gravity birm filters	Spray nozzles, coke tray aeration; gravity birm filter (filtered water alkalinized)
Aeration:			
Equipment	4 four-inch coke trays	2 six-inch coke trays	2 spray nozzles and 2 six-inch coke trays
Rate, *g.p.m. per sq.ft.*	7.5	1.5	2.5
Filtration:			
Equipment	1 pressure filter	2 gravity filters	1 gravity filter
Area, *sq.ft.*	28	15.75 (each)	12.5
Birm sand, *in.*	36	30	36
Rate, *g.p.m. per sq.ft.*	4	1.25	1.75

Operation Results

	Oakdale Raw	Oakdale Filter	Oakdale Tap	Sligo Raw	Sligo Filter	Sligo Tap	Shippenville Raw	Shippenville Clear Well	Shippenville Tap
Color, *p.p.m.*	50.	0.	—	10.	0.	0.	100.	10.	0.
Turbidity, *p.p.m.*	40.	0.	—	10.	0.	0.	75.	10.	0.
Total residual, *p.p.m.*	680.	700.	—	515.	510.	485.	125.	139.	137.
pH	7.5	7.6	—	7.1	7.7	7.7	6.2	8.4	8.3
Chlorides, *p.p.m.*	52.	54.	—	150.	150.	150.	11.	16.	17.
Oxygen consumed, *p.p.m.*	—	—	—	1.6	0.4	0.6	0.8	0.5	0.5
Total hardness, *p.p.m.*	380.	380.	—	106.	87.	82.	80.	76.	75.
Alkalinity, *p.p.m.*	195.	190.	—	190.	195.	190.	76.	91.	86.
CO_2, *p.p.m.*	55.	19.	—	33.	14.	11.	109.	0.	0.
Dissolved oxygen, *p.p.m.*	0.	8.4	—	0.03	6.7	5.5	0.25	6.8	2.45
Total iron, *p.p.m.*	2.0	0.	—	1.0	0.3	0.2	20.	0.3	0.3
Mn, *p.p.m.*	1.7	1.7	—	0.	0.	0.			
Temperature, *deg. F.*	57.	—	—	52.	—	—	63.	—	—

* One determination.

treatment with a water containing objectionable amounts of iron and manganese. Likewise, at least for some waters, birm has no advantage over silica sand (which costs considerably less), especially if aeration is required before filtration.

Coke Contact Aeration and Sand Filtration

Coke contact aeration and sand filtration (Table 3) as a method of iron removal, where applicable, is simple and probably as fool-proof as any of the iron removal schemes, especially for the smaller plants. Thorough aeration is required to effect satisfactory removal of the carbon dioxide which holds the iron in solution. The coke becomes coated with a heavy iron precipitate which acts to remove more iron from the water as it is aerated. The sand in the filters likewise acts to remove the iron remaining after aeration. Coke tray aerators will give high carbon dioxide removals even when operated at high rates. With well waters containing large amounts of iron, the coke tends to slime over, thereby affecting distribution of the water through the aerator and removal of carbon dioxide. The surface of the coke in the trays needs to be raked lightly or flushed at intervals to overcome this difficulty. It is desirable for the smaller plants, handling waters of higher iron contents, to use low aeration rates.

Many of the Western Pennsylvania ground waters contain some hydrogen sulfide which is removed at the same time as the carbon dioxide. The aeration structure should be designed to effect the removal of the gases swept out during aeration. Aeration at the Seneca and Knox installations effects a carbon dioxide reduction of about 80 per cent. The filter sand at both of these installations accumulates considerable iron on the sand between filter washes and the wash water requirements are high, close to 10 per cent at the Seneca plant. It would appear desirable to use a coarser filter sand than is ordinarily used and to equip filters handling waters of the higher iron contents, with either a combined air and wash water or a supplemental surface wash. For the high iron waters it would be desirable to provide the plant with a settling basin to catch oxidized iron washed from the coke, as well as lime feed facilities for use if desirable. It is questionable whether coke tray aeration and sand filtration without supplemental treatment would be satisfactory for waters containing any significant amount of manganese in addition to iron.

TABLE 3

Design and Operation of Coke Contact Aeration Sand Filtration Plants

	SENECA	KNOX
Raw Water Quality		
pH	6.0– 6.3	6.4– 6.8
Alkalinity, *p.p.m.*	48. – 76.	94. –120.
Hardness, *p.p.m.*	72. –120.	80. –100.
CO_2, *p.p.m.*	— –122.*	35. – 58.
Fe, *p.p.m.*	8.0– 21.	1.6– 5.0
Mn, *p.p.m.*	0. – 1.0	0.1– 0.4
Design and Operation Data		
Source of supply	Well	Wells
Treatment	Coke tray aeration, gravity sand filter (filtered water alkalinized)	Coke tray aeration, gravity sand filters
Aeration:		
Equipment	4 ten-inch coke trays	3 eight-inch coke trays
Rate, *g.p.m. per sq.ft.*	1.5	1.0
Filtration:		
Equipment	2 gravity filters	2 gravity filters
Area, *sq.ft.*	12.5 (each)	39.0 (each)
Rate, *g.p.m. per sq.ft.*	1.0	1.5

Operation Results

	Seneca Raw	Seneca Filter effluent	Seneca Tap	Knox Raw	Knox Filter	Knox Tap
Color, *p.p.m.*	100.	0.	0.	60.	0.	10.
Turbidity, *p.p.m.*	100.	0.	0.	45.	0.	10.
Total residual, *p.p.m.*	175.	150.	175.	260.	230.	230.
pH	6.2	6.7	8.25	6.5	7.1	7.4
Chlorides, *p.p.m.*	27.	27.	27.	60.	57.	57.
Oxygen consumed, *p.p.m.*	0.5	0.3	0.2	0.4	0.3	0.3
Total hardness, *p.p.m.*	100.	68.	60.	88.	80.	82.
Alkalinity, *p.p.m.*	58.	55.	90.	108.	105.	106.
CO_2, *p.p.m.*	122.	27.	0.	58.	12.	7.
Dissolved oxygen, *p.p.m.*	0.5	8.5	7.5	0.25	7.3	5.5
Total iron, *p.p.m.*	10.	0.1	0.1	4.5	0.1	0.1
Mn, *p.p.m.*	—	—	—	0.3	0.1	0.1
Temperature, *deg. F*	49.	—	—	57.	—	—

* One determination.

Manganese Zeolite Plants

Manganese zeolite (Table 4) is a special prepared zeolite that has the ability to remove ferrous iron and manganese from water. Potassium permanganate is used to regenerate the zeolite after it is washed to secure removal of the retained oxides of iron and manganese. This zeolite, however, does not soften water. The Edgeworth and Coraopolis plants combine sodium zeolite softening with manganese zeolite iron and manganese removal for that part of the water that is not softened. The Fryburg installation is for iron removal only. The Edgeworth manganese filter handles a raw water containing about 2 p.p.m. combined iron and manganese and is operated as an upward flow filter at a high rate, 6 g.p.m. per sq.ft.

In four years of operation of the plant, the zeolite sand grains in the filters have increased in size due to deposited manganese. This change, however, does not appear to have affected its capacity for iron and manganese removal, but it has been necessary on several occasions to remove some of the coated zeolite and to replace it with new material to maintain proper freeboard and to prevent loss of material. This experience seems to indicate that down-flow filters are to be given preference in treating waters containing manganese. The up-flow units at Edgeworth are operated at two to three times the filter rate of the Coraopolis down-flow filters and the operation results are comparable. These filters use about 2.1 lb. potassium permanganate for each pound of combined iron and manganese removed in regenerating the zeolite.

The Coraopolis manganese filters are downward flow pressure filters, operated at a rate of about 2 g.p.m. per sq.ft. The samples collected at the plant show low manganese removals, in all probability due to the fact that the samples were collected shortly before the units were to be regenerated. The filters in this plant use approximately the same amount of potassium permanganate as those of the Edgeworth plant.

The Fryburg plant operates on a high-iron water at a high rate and the performance of these units has not been satisfactory, even though the well water is partially aerated and settled prior to filtration. The Fryburg installation removes a substantial part of the iron, but the filtered water is quite corrosive, as evidenced by the typical chemical results of the tap sample. Facilities for pH correction of the finished water have not been installed at this plant.

TABLE 4

Design and Operation of Manganese Zeolite Plants

	EDGEWORTH	CORAOPOLIS	FRYBURG
Raw Water Quality			
pH	7.3– 7.7	7.3– 7.6	6.2– 6.6
Alkalinity, *p.p.m.*	85. –100.	70. –100.	58. – 85.
Hardness, *p.p.m.*	130. –180.	140. –260.	74. –110.
CO_2, *p.p.m.*	10. – 15.	20. – 25.	50. – 87.
Fe, *p.p.m.*	0.5– 0.6	0.3– 0.60	1.6– 20.
Mn, *p.p.m.*	1.1– 2.6	0.7– 1.2	0.1– 0.7
Design and Operation Data			
Source of supply	Wells	Wells	Wells
Treatment	Open permanganate zeolite filter, up-flow	Pressure downflow permanganate zeolite filter (filtered water alkalinized)	Aeration, settling; pressure permanganate zeolite filters
Filtration:			
Area, *sq.ft.*	66.	125.	2.75
Rate, *g.p.m. per sq.ft.*	6.0	2.1	6.0

Operation Results

	EDGEWORTH Raw	EDGEWORTH Filter	EDGEWORTH Tap*	CORAOPOLIS Raw	CORAOPOLIS Filter	CORAOPOLIS Tap*	FRYBURG Raw	FRYBURG Filter	FRYBURG Tap
Color, *p.p.m.*	10.	5.	0.	5.	0.	0.	75.	5.	10.
Turbidity, *p.p.m.*	10.	5.	0.	5.	0.	0.	75.	5.	20.
Total residual, *p.p.m.*	265.	260.	265.	325.	340.	325.	150.	135.	135.
pH	7.6	7.6	8.0	7.2	7.2	7.6	6.5	6.3	6.3
Chlorides, *p.p.m.*	15.	15.	18.	28.	28.	28.	5.	5.	5.
Oxygen consumed, *p.p.m.*	1.0	1.0	1.0	0.6	0.6	0.6	0.2	0.	0.
Total hardness, *p.p.m.*	180.	200.	90.	230.	240.	76.	90.	90.	98.
Alkalinity, *p.p.m.*	95.	90.	100.	100.	100.	100.	69.	69.	70.
CO_2, *p.p.m.*	10.	12.	12.	20.	20.	2.	87.	58.	56.
Dissolved oxygen, *p.p.m.*	0.	0.	3.9	0.	0.8	6.0	0.	3.4	0.2
Total iron, *p.p.m.*	0.6	0.2	0.2	0.3	0.	0.	9.	0.4	2.3
Mn, *p.p.m.*	1.5	0.05	0.	0.7	0.4	0.05	0.3	0.3	0.05
Temperature, *deg. F.*	59.	—	—	60.	—	—	55.	—	—

* Mixture of zeolite-softened and hard water with Fe and Mn removed.

Operation results have indicated that the filters are overloaded at times of high iron content in the raw water, due to the high (6 g.p.m. per sq.ft.) operation rate of the filters.

Lime Treatment and Filtration

The addition of lime in amount sufficient to neutralize the carbon dioxide and maintain a pH of 8.2 to 8.4 will precipitate iron as an insoluble hydrate. Lime can be used to remove iron from water, where the iron is in either carbonate or sulfate form. Most Western Pennsylvania ground waters containing ferrous iron as carbonate are high in carbon dioxide, so, for reasons of economy, when lime is used, it is desirable first to aerate the water for carbon dioxide reduction, neutralizing the remaining quantity with lime. Aeration is required in some instances to remove hydrogen sulfide. Lime treatment and filtration (Table 5) may be selected in those cases where the iron exists as sulfate, where iron content is high, where iron and manganese removal are required without softening or where part of the water is softened with zeolite, and iron and manganese are removed in the unsoftened part of the water to maintain a combined water of satisfactory hardness and mineral content.

The raw waters at the Ambridge and Duquesne plants, selected to illustrate lime treatment, contain low amounts of iron but high manganese contents. The lime treatment does not increase the hardness at these plants. Liming to the point of manganese removal results in considerable softening by removing carbonate hardness as evidenced by the Ambridge results. This factor must be considered, especially in waters where carbonate hardness is high, when comparisons are made of various treatment possibilities. It is interesting to note the difference in pH at which manganese is removed at the two plants. Ambridge maintains a pH of 9.2 to 9.4 to precipitate the manganese, whereas at the Duquesne plant pH is kept at 8.0. Some deposition of manganese has taken place on the filter sand at the Ambridge plant, and the anthrafilt medium at the Duquesne plant is heavily coated with carbonates, iron and manganese. Anthrafilt as such is not distinguishable in the filters because of the heavy coating. The medium has increased 50 to 100 per cent in size since it was installed. Part of the manganese is being removed by contact action with the coated anthrafilt. With a high manganese water it undoubtedly is better practice to remove manganese by chemical treatment rather than by contact with the filter media.

TABLE 5

Design and Operation of Lime Treatment and Filtration Plants

	AMBRIDGE			DUQUESNE		
Raw Water Quality						
pH	6.8– 7.2			6.2– 7.1		
Alkalinity, *p.p.m.*	69. –100.			40. – 60.		
Hardness, *p.p.m.*	120. –350.			160. –220.		
CO_2, *p.p.m.*	15. – 33.			20. – 70.		
Fe, *p.p.m.*	0.6– 1.2			0.3– 4.0		
Mn, *p.p.m.*	3.8– 8.0			1.8– 10.0		
Temperature, *deg. F.*	44. – 65.			52. – 82.		
Design and Operation Data						
Source of supply	Wells			Wells		
Treatment	Aeration, lime treatment; settling and filtration			Aeration, lime treatment; settling and filtration		
Settling time, *hr.*	2.5			3.75		
Filtration:						
Area, *sq.ft.*	192.			360.		
Rate, *g.p.m. per sq.ft.*	2.0			2.0		
Operation Results						
	Raw	Filter	Tap*	Raw	Filter	Tap
Color, *p.p.m.*	5.	5.	5.	50.	0.	5.
Turbidity, *p.p.m.*	5.	5.	5.	20.	0.	5.
Total residual, *p.p.m.*	550.	460.	525.	460.	450.	440.
pH	7.0	9.4	7.5	6.5	8.0	8.2
Chlorides, *p.p.m.*	32.	32.	54.	37.	37.	37.
Oxygen consumed, *p.p.m.*	0.5	0.7	0.8	1.0	0.8	1.0
Total hardness, *p.p.m.*	350.	270.	76.	220.	190.	220.
Alkalinity, *p.p.m.*	100.	30.	80.	53.	37.	33.
CO_2, *p.p.m.*	33.	0.	12.	56.	0.	0.
Dissolved oxygen, *p.p.m.*	0.	4.4	5.6	0.	2.7	—
Total iron, *p.p.m.*	0.8	0.	0.	3.0	0.	0.
Mn, *p.p.m.*	6.0	0.	0.	6.0	0.05	0.
Temperature, *deg. F.*	62.	—	—	72.	—	—

* Combined lime treated and zeolite softened water.

Lime or Lime-Soda Softening

In some cases the raw water may be hard in addition to containing objectionable amounts of iron or iron and manganese. Iron removal in itself would not be justified, as the treated water would still be objectionable from the hardness and manganese standpoints. Lime or lime-soda softening (Table 6) may be selected to soften the water

TABLE 6

Design and Operation of Lime or Lime-Soda Softening Plants

	GROVE CITY			SHALER TOWNSHIP		
Raw Water Quality						
pH	7.0 - 7.4			7.0- 7.5		
Alkalinity, *p.p.m.*	160. -176.			100. -280.		
Hardness, *p.p.m.*	140. -200.			130. -340.		
CO_2, *p.p.m.*	10. - 30.			— —		
Fe, *p.p.m.*	1.0 - 4.0			1.5- 7.0		
Mn, *p.p.m.*	0.05- 0.5			0.4- 1.0		
Design and Operation Data						
Source of supply	Wells			Wells		
Treatment	Aeration, lime-soda softening, filtration			Aeration, lime softening, precipitator filtration		
Settling time, *hr*	6.0			4.5		
Filtration:						
Area, *sq.ft.*	600.			170.		
Rate, *g.p.m. per sq.ft.*	2.0			2.0		
Operation Results						
	Raw	Filter	Tap	Raw	Filter	Tap
Color, *p.p.m.*	90.	0.	0.	75.	0.	0.
Turbidity, *p.p.m.*	65.	0.	0.	50.	0.	0.
Total residual, *p.p.m.*	295.	180.	170.	300.	280.	275.
pH	7.2	9.3	9.0	7.3	9.6	9.6
Chlorides, *p.p.m.*	11.	12.	12.	22.	21.	22.
Oxygen consumed, *p.p.m.*	0.7	0.	0.2	2.4	3.3	2.9
Total hardness, *p.p.m.*	175.	74.	78.	210.	170.	170.
Alkalinity, *p.p.m.*	160.	64.	67.	110.	80.	80.
CO_2, *p.p.m.*	25.	0.	0.	—	—	—
Dissolved oxygen, *p.p.m.*	—	8.65	6.7	—	—	—
Total iron, *p.p.m.*	1.7	0.	0.	2.0	0.	0.
Mn, *p.p.m.*	0.2	0.	0.	0.4	0.	0.

and, at the same time, remove iron and manganese. The Grove City and Shaler Township plants are examples of this treatment. Iron or iron and manganese removal is effected by this treatment in the same way as by lime treatment alone. The Shaler Township plant is equipped with a precipitator, and, ordinarily, the hardness of the finished water is maintained at about 110 p.p.m. The results of analyses given in the table, under "Operation Results," were from samples collected at a time when the precipitator was not being operated because of mechanical difficulties. Complete iron and manganese removal are secured at these plants.

Summary

Well waters serve as the source of many Western Pennsylvania public water supplies. With the exception of several instances, where water supplies are secured from glacial drift in northwestern Pennsylvania and from the river gravel in, and along, the Ohio and Allegheny Rivers near Pittsburgh, well waters generally supply the smaller communities. These well waters are usually hard, contain high amounts of carbon dioxide and little or no dissolved oxygen and contain iron or iron and manganese in varying amounts. There is considerable variation in the iron or iron and manganese contents of well waters at a particular installation where there are a number of wells of similar construction penetrating the same formation.

The problem of providing iron removal facilities should be considered from the standpoint of the chemical quality of the water to be treated and the size of the installation. The small plants lack skilled operators and such plants should be as simple and foolproof as possible even to the extent of using low operating rates in preference to more complicated facilities, so that operating simplicity can be maintained. All of the methods of iron removal have their own particular advantages. Sodium zeolite, for instance, accomplishes complete removal of ferrous iron and manganese, in addition to softening during the softening run. It also effects iron, or iron and manganese, removal in varying amounts through the twilight zone. There is a definite relation between the hardness curve of water passing through the zeolite during the twilight zone to complete hardness and the iron and manganese content of the filtered water. There undoubtedly is a limit to the amount of iron or manganese, or both, that zeolite should handle for satisfactory performance and,

as indicated by the Ambridge experience, a limit to the overrun with a water of high manganese content.

Coke tray aeration, preceding birm filtration at the installations considered, secured a carbon dioxide removal of about 60 per cent or better, increased the pH of the well water to a minimum of 6.9 and increased the dissolved oxygen content from an average of nearly zero to about 8.0 p.p.m. Satisfactory reduction of iron is effected with filter rates ranging from 1.25 at Sligo to 4 g.p.m. per sq.ft. at Oakdale. No manganese reduction was obtained with this material at Oakdale, which would indicate the desirability of limiting the material to waters containing iron only. It is doubtful whether

TABLE 7

Operation Data on Coke Tray Aerators

PLANT	CO_2 CONTENT		REDUCTION	AERATION RATE	DISSOLVED OXYGEN	
	Raw Water	Aerated Water			Raw Water	Aerated Water
	p.p.m.	*p.p m.*	*%*	*g.p.m. per sq.ft.*	*p.p.m.*	*p.p.m.*
Coraopolis	20.	8.	60	25.	0.3	6.0
Oakdale	55.	19.	65	7.5	0.	8.0
Shippenville	109.	42.	60	2.5	0.25	8.5
Sligo	33.	14.	60	1.5	0.05	7.2
Seneca	122.	27.	78	1.5	0.5	8.5
Knox	58.	12.	80	1.0	0.1	8.3

this material has any decided advantage, at least for some waters, over silica sand filtration, especially if aeration is required preceding filtration.

Manganese zeolite at the Edgeworth and Coraopolis installations is effecting satisfactory removal of iron and manganese in these well waters, which contain about 2 p.p.m. or less of combined iron and manganese. The Edgeworth filter is operating as an up-flow filter at a high rate with some continued deposition of manganese on the zeolite grains, as against the Coraopolis filters which are down-flow filters, operating at about 2 g.p.m. per sq.ft., with some manganese deposition on the zeolite grains, which does not seem to increase with continued use. The Fryburg installation has high rate filters and operates on a high-iron water. These filters are overloaded on the high iron, and the installation indicates the necessity of installing

facilities for corrosion control as an essential part of some iron removal plants.

The coke contact aeration and sand filtration installations are satisfactorily handling waters ranging from medium to high iron contents with filter rates ranging from 1 to 1.5 g.p.m. per sq.ft. Installing coarser sand and air or surface wash facilities, with possibly a settling tank for the higher iron waters, would appear desirable. Table 7 gives the operation data on the coke tray aerators.

The lime treatment, sedimentation and filtration installations showed practically a complete removal of iron and manganese. The lime treatment, in the case of Ambridge, is also effecting a 25 per cent reduction in hardness as against a lower hardness reduction at the Duquesne installation.

The aeration, lime or lime-soda softening installations likewise effect complete removal of iron and manganese during the softening process. All of the carbon dioxide is removed or neutralized during the treatment.

Studies on the Accuracy of Threshold Odor Values

By Roberts Hulbert and Douglas Feben

FREQUENTLY enough in the history of science, theories have been abandoned in the light of new facts. This is never a reflection on the authors of the theories, for invariably their work has been the stepping stone toward new experiments, new discoveries and progress. Yet such progress is never any more rapid than the time it takes to divest ourselves of encumbering ideas, once it has been shown that they conflict with ascertained facts. It is the purpose of this paper to describe some experiments, the results of which show that, contrary to widespread opinion, the human sense of smell is totally unreliable as a means for estimating odor concentrations quantitatively, with any acceptable degree of accuracy.

The experiments described herein were the outcome of failure to secure acceptable results from co-operative work performed in various Michigan water laboratories, based upon an assignment of the A.W.W.A. Activated Carbon Research Committee of 1938–39. This assignment had to do with the comparative evaluation of four different phenol-value carbons by the threshold odor method, using raw waters of various taste and odor types. In order to secure unbiased results, the following procedure was adopted:

The four test carbons were coded, and a sample of each sent to four laboratories, each of which agreed to run odor adsorption tests, using a uniform, stipulated procedure with its own raw water. The results were returned to the Detroit Laboratory, where the carbons were ranked according to their efficiency in each comparative test. This procedure was followed three times at intervals of a month, the carbon samples being recoded each time, making a total of 48 evaluations, or three trials for each carbon at each of the four laboratories.

A paper presented on September 25, 1941, at the Michigan Section Meeting, Grand Rapids, Mich., by Roberts Hulbert, Assistant Superintendent and Douglas Feben, Senior Sanitary Chemist, Filtration Plant, Detroit.

The results are shown in Table 1, in which the average threshold odor units adsorbed per unit weight of carbon are used to rank the various carbons. It is these average ranking values which have the greatest significance.

It can be shown mathematically that if the carbons were represented by four different playing cards, shuffled and dealt blindfolded, there would be 24 possible combinations representative of the order in which they could appear. Likewise, it can be shown that if the

TABLE 1

Comparative Evaluation of Four Carbons by Threshold Technique

CITY	TRIAL	CARBON A PV 20		CARBON B PV 16		CARBON C PV 14		CARBON D PV 20	
		Ave. X/M*	Rank	Ave. X/M	Rank	Ave. X/M	Rank	Ave. X/M	Rank
Flint	1	1.987	3	2.010	1	1.995	2	1.947	4
	2	2.125	2	1.790	3.5	2.250	1	1.790	3.5
	3	1.195	1	1.095	2.5	1.058	4	1.095	2.5
Saginaw	1	2.148	1	1.929	2	1.549	4	1.616	3
	2	0.878	4	1.005	3	1.398	1	1.155	2
	3	0.840	4	1.160	1	0.940	2	0.850	3
Highland Park	1	0.800	2	0.732	4	0.892	1	0.768	3
	2	0.956	4	0.988	3	1.042	2	1.312	1
	3	1.290	2	1.408	1	1.216	3	1.010	4
Ann Arbor	1	2.025	3	1.987	4	2.205	2	2.507	1
	2	1.280	2	1.035	3	0.707	4	1.295	1
	3	1.151	1	0.852	3	0.815	4	1.020	2
Totals.		16.675	29	15.991	31	16.067	30	16.365	30
Average.		1.39	2.42	1.33	2.58	1.34	2.50	1.36	2.50

* Average threshold odor units adsorbed per unit weight of carbon.

cards were dealt out in this manner a sufficient number of times, and if a record were kept of the order in which any given card was turned up, i.e. first, second, third or fourth (1, 2, 3 or 4), the average of the values would be 2.5.

In the case of the four carbons, 12 trials in all were made, just half the minimum number required for all possible combinations of order to appear; yet the probability value of 2.5 is already apparent in the average results obtained. Plainly, the conclusion is warranted that

the results summarized in Table 1 are fortuitous, merely the result of chance, and actually furnish a fair demonstration that the threshold method used in these trials gave no more scientific basis for the selection of carbons than that contained in the analogy of the playing cards. For the 12 carbon assays given in this table, no two laboratories ever agreed on the same ranking of the four carbons, notwithstanding the fact that the test samples were purposely selected as being different on the basis of their phenol adsorptive capacity after determination by chemical analysis. The obvious conclusion is that the threshold test employed in this work is subject to errors considerably greater than the differences between the carbons tested.

Procedure of Studies

The disappointing results of this co-operative work suggested the desirability of proceeding with research work specifically planned to measure the accuracy of odor determinations by the threshold procedure. The error involved in any instrument or laboratory method is a fundamental consideration in judging its usefulness for any specific purpose. This applies to the human nose as the instrument, and the threshold method as a laboratory technique for measuring odor quantitatively.

To measure the variability of any one factor, all other possible variants must, of course, be maintained constant during any one experiment. Applying this rule to the problem at hand, it was necessary to work with a standard odor solution throughout. For this purpose a large quantity of Clinton River water was brought to the laboratory and stored for many weeks to enable it to reach a stable condition. Before using the water in the experiments it was carefully decanted to give a turbidity-free stock, so that no clue to the extent of dilution in the flask, as it was presented to the observer, would be revealed visually.

With this prepared stock odor-water, nine individual tests were made in five different water plant laboratories, the same procedure being followed in each case. Each observer was required to determine the threshold value of the stock sample, and also of four known (but unknown to the observer) dilutions of the stock, the diluent in each case being odor-free water. Thus, for any given observer, the comparative threshold values of the four dilutions could be calculated from the value experimentally obtained for the undiluted sample by the observer.

The diluted samples consisted of 750, 600, 300, and 150 ml. portions of the stock water diluted to 1 liter. These dilutions, then, represented threshold values, respectively, of 75, 60, 30 and 15 per cent of that of the undiluted, odorous water. If, for instance, an observer obtained a threshold value of 40 for the stock sample, then he should have obtained 30 for the first dilution, 24 for the second, etc. If, then, his reactions were such that a threshold of 20 instead of 30 was returned against the first dilution, then his error would be 33 per cent for that determination. Needless to say, all observers were required to work on a strictly blindfold basis.

TABLE 2

Threshold Value Determinations by Different Observers on Standard Dilutions

DATE, 1939	OBSERVER	THRESHOLD VALUE UNDILUTED STOCK	THRESHOLD VALUES AND ERRORS AT DILUTION STRENGTHS														
			75%			60%			30%			15%			Error %		
			Actual	Found	Error %	Actual	Found	Error %	Actual	Found	Error %	Actual	Found	Error %	Average	Maximum	Minimum
5-3	L. D.	50	37.5	65	74	30	28	7	15	11	27	7.5	3.75	50	39	74	7
5-4	W. D.	240	180	90	50	144	180	25	72	18	75	36	12	67	54	75	25
5-5	M. D.	8	6	3.5	42	4.8	1.2	75	2.4	2	17	1.2	1	17	38	75	17
5-9	P. F.	28	21	12	43	16.8	16	5	8.4	5	40	4.2	2.5	41	32	43	5
5-9	S. S.	12	9	10	11	7.2	12	67	3.6	18	400	1.8	14	677	289	677	11
5-10	F. D.	6	4.5	4.5	0	3.6	2.5	44	1.8	1.2	50	0.9	1.6	78	43	78	0
5-11	D. H.	10	7.5	5	33	6.0	6	0	3	4.5	50	1.5	4.5	200	71	200	0
5-12	M. A.	9	6.75	5	35	5.4	6	10	2.7	5	46	1.35	8	492	146	492	10
5-12	M. A.	12	9	10	11	7.2	10	39	3.6	6	67	1.8	4	122	60	122	11

Results of Studies

The results of these tests are shown in Table 2, and, as indicated by the dates, are given chronologically. The extreme variation in the threshold values for the undiluted stock water may be accepted as evidence of the extreme range of sensitivity to odor exhibited by different observers. In the case of the threshold odors of the dilutions, the values in the column labeled "Actual" are those which the observer should have obtained, based upon his particular value for the stock sample. The columns marked "Found" are the values obtained by his reactions to successive sub-dilutions. For each observer, without exception, there is evidence of a great change in sensitivity occurring even during the short time required to complete one of these tests. The errors listed in the table are not absolute;

they are merely comparative, inasmuch as the assumption was made that the first determination of any observer was correct.

These findings substantiate the conclusions recorded in the first part of this paper, and when circulated among the committee members elicited no criticism other than a reference to the use of raw, sewage polluted water as a stock odor-bearing solution. It was pointed out that the odorous substances present may have been of such a nature that dilution caused some marked changes therein, such as hydrolysis, dissociation, or the like, and that if such changes took place they could be responsible for the errors found.

Helbig* pointed out that in some independent research conducted by him, in which several known, pure compounds were used, it was found that certain substances exhibited such a behavior, failing to give consistent results, while others, notably phenol, were stable and therefore recommended as perfectly suitable for odor research.

Modification of Threshold Procedure

At about this same time, Spaulding, in a communication to the Carbon Committee, recommended that the threshold procedure be modified in such a manner as to give recognition to the inconsistencies which occur. He proposed that, after a few trial dilutions to establish the approximate threshold level, the observer be presented with a series of flasks to smell, in which some dilutions are repeated at intervals until a definite pattern is built up as in Fig. 1, in which the letters represent dilutions. The highest dilution, which yields three positives out of three trials is called the base positive dilution. Above this base are four successively higher dilutions constituting a so-called "twilight zone." In the next higher dilution above the base there are to be three trials, one of which must be negative. In the second higher dilution there are to be two trials, and in each of the next two dilutions, one trial each. In these last three dilutions the results can be either positive or negative. A final requirement of this proposed modified procedure is that not more than 50 per cent of the observations in the twilight zone shall be positive.

Higher dilutions decreasing odor ↑

E±
D±
C±±
B−±±
A+++

FIG. 1

This proposed modification of the threshold procedure is a definite

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* HELBIG, W. A. A Uniform Basis for Activated Carbon Comparison. Jour. A. W. W. A., **31**: 1931 (1939).

concession to the inaccuracies inherent in the test, but, more than that, the recognition of a twilight zone makes available for the first time a method whereby the error of a threshold determination can be measured accurately. To do this it is essential that the twilight zone be defined as to nature and extent.

TABLE 3

Summary of Data on 100 p.p.m. Phenol Test Solution

OBSERVER	*Gp* VALUES			MAX. DEVIATION FROM AVE.	NUMBER OF DILUTIONS IN TWILIGHT ZONE FOR — Dilution tables used				
	Ave.	Max.	Min.		10%	20%	30%	40%	50%
				%					
A	10.0	23.5	2.8	135	4	3	7	1	2
					10	2	2	3	3
					12	3	4	1	1
					6	3	2	2	1
B	5.9	13.7	1.3	132	16	12	1	2	1
					14	9	4	1	2
					24	9	3	3	3
					16	6	3	3	3
C	1.8	3.6	0.01	100	18	3	6	8	2
					5	6	3	3	3
					13	4	11	3	1
					8	11	4	4	2
D	17.0	40.0	5.9	135	12	5	5	1	4
					10	8	1	3	2
					3	5	3	2	2
					3	7	1	2	2
Averages					10.9	6.0	3.75	2.62	2.12

Since "twilight" is defined as "a region of indistinct apprehension or perception," and a "zone" as "a belt or area delimited from others and separating two regions of unlike characteristics," the term "twilight zone" is well applied; it is that region separating that which is distinctly positive from that which is distinctly negative. Obviously the olfactory twilight zone will be bounded at one end by that dilution at which an indefinite number of observations will all be rendered positive but immediately above which will be a dilution for

which at least one observation will be negative. Since it is impractical to make an indefinite number of observations at one dilution, Spaulding's choice of three trials seems satisfactory. It must be pointed out, however, that *all* observations at *all* lower dilutions than this base dilution should also be positive. Here again an indefinite number of observations is out of the question, and it is suggested that a compromise be made by requiring one positive out of one trial at each of the three successively lower dilutions below the base dilution, thus yielding the pattern shown in Fig. 2. This is a necessary requisite, for it has been found experimentally that quite frequently a negative observation will be returned against a lower dilution than that already established as a tentative base.

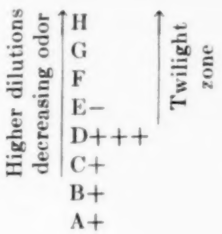

FIG. 2

Now, by the same reasoning, the other end of the twilight zone, the negative base dilution, can be defined in like manner; i.e., as that dilution at which is secured three negatives out of three trials, and immediately below which is a dilution in which at least one of the observations is a positive one. Similarly, above this negative base dilution there should be one negative out of one trial for each of the three next higher dilutions. Thus results a pattern such as is shown in Fig. 3, and the extent of the twilight zone is measured by the number of dilution steps separating the negative and positive base dilutions; e.g., in the figure, the twilight zone is eight dilution steps wide.

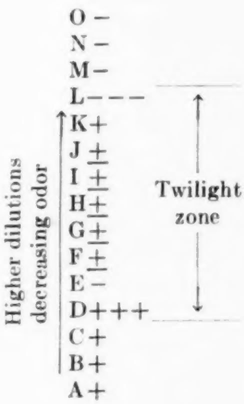

FIG. 3

The width of the twilight zone in any one test may be dependent on several factors, but the most important of these is the percentage reduction in odor concentration between adjacent dilutions. It is almost axiomatic that if a dilution table be prepared in which the percentage reduction in adjacent dilutions is 40 per cent, a shorter twilight zone will

result than that from a 10-per cent dilution table. It was the purpose of this study to determine the relation between the width of the twilight zone and the percentage differences used in a dilution table, as this would show what percentage dilution steps are necessary to produce a minimum twilight zone width, such as is shown in Fig. 4. The minimum percentage reduction used in a dilution table giving such results would be twice the probable error involved in the determination of any threshold odor value.

Higher dilutions decreasing odor ↑

H −
G −
F −
E − − −
D + + +
C +
B +
A +

FIG. 4

Five dilution tables, in which the percentage reductions in adjacent dilutions were 10, 20, 30, 40, and 50, were compiled. Four observers were used, each being tested four times with each of the five dilution tables. One man prepared dilutions and recorded results, and a second man brought the flasks to the proper temperature and presented them to the observer. The observer, of course, worked blindfolded, i.e., he was not allowed to know which flask was odor-bearing, nor which dilution table was being used. The entire test was made with a 100 p.p.m. phenol solution, measured out with an automatic burette. Dilution water was carbon-treated, distilled water, and all the work was done at 50°C. This temperature was selected as giving the maximum values at continuous comfort to the observer.

Accuracy of Threshold Procedure

In Helbig's work, previously referred to, he uses the term "*Gp*" to express the gravimetric concentration of phenol at the threshold of odor perceptibility. Owing to this direct relationship, this *Gp* value is just as indeterminate as the threshold value, but, by taking the average of the two *Gp* values represented by the negative and positive base dilutions, a mean *Gp* value for any one test is secured. A brief summary of these values is given in Table 3.

The first striking feature of this part of the summary is that all observers were on markedly different levels of odor perceptibility, ranging from a *Gp* value of 1.8 to one of 17.0. Next it will be noticed that all observers showed a marked variation in their own sensitivity, the maximum deviation being 100 per cent or more from their own average. A marked change in sensitivity occurs, not only from one complete test to another, but frequently even in the short time which elapses between smelling successive flasks.

The accuracy of the threshold odor determination is not any better than that represented by the percentage reduction in adjacent dilutions when the twilight zone is one dilution step in width. If the twilight zone is wider than this, the error involved is greater than that represented by the percentage reduction in adjacent dilutions. A dilution table in which the percentage reduction is a constant represents an infinite geometric series, to which definite mathematical rules apply. Application of these rules makes possible the following analysis of these data, which resulted from an experiment based on such a series.

If we let a represent the number of milliliters of sample diluted to standard volume, and p the percentage reduction in adjacent dilutions, then the quantity of sample, in milliliters, in that dilution one step higher (weaker) than a will be $\frac{a(100 - p)}{100}$, and the quantity of sample, in milliliters, contained in that dilution n steps from a is $\frac{a(100 - p)^n}{100^n}$ or $a\ (1 - 0.01\ p)^n$.

Now, if a twilight zone is n dilution steps wide, and the quantity of sample in the positive base dilution is a, the difference between the positive and negative base dilutions, in milliliters, will be $a - a\ (1 - 0.01\ p)^n$, which, expressed as percentage of a will be $\frac{100\ [a - a(1 - 0.01p)^n]}{a}$ or $100[1 - (1 - 0.01\ p)^n]$; and this expression will represent the maximum error on a percentage basis for any observation. Applying this equation to the average results given in Table 3, we obtain the following:

REDUCTION IN ADJACENT DILUTIONS	NO. OF DILUTION STEPS IN TWILIGHT ZONE	AVE. MAXIMUM ERROR (E)
%		
10	10.9	68.3
20	6.0	73.8
30	3.75	73.8
40	2.62	73.8
50	2.12	77.0
Average		73.3

By writing the equation for percentage error as $E = 100\ [1 - (1 - 0.01\ p)^n]$ and substituting the average value of 73.3 for E and transposing, we obtain $p = 100\ (1 - \sqrt[n]{0.267})$, which will be the equa-

tion of the curve obtained by plotting p (percentage reduction in adjacent dilution) against n (number of dilutions in twilight zone). This curve is shown in Fig. 5, and the points representing the experimental data fit the curve satisfactorily. The conclusion derived from these results is that, regardless of what percentage dilution table is used for any threshold determination, the probable error will be half the average maximum error, i.e., plus or minus 36.5 per cent.

This probable error is greatly in excess of that which was anticipated when the threshold method was first recommended, and, in view of this, it was decided to consider a different approach to the same

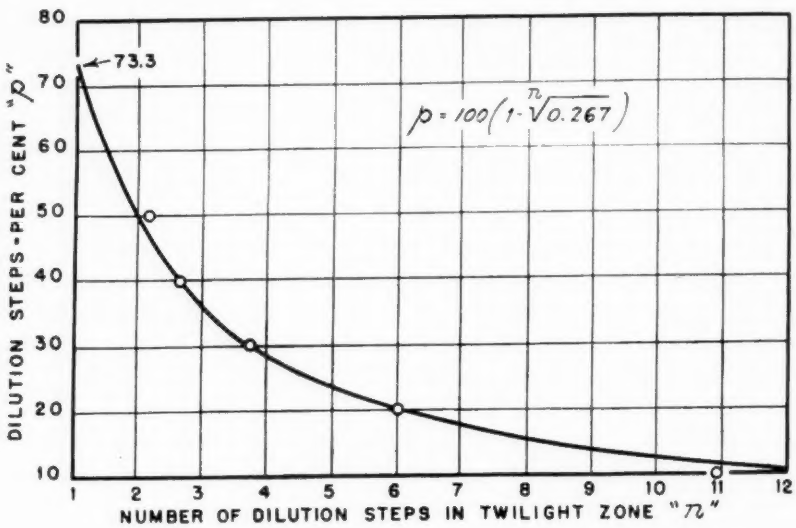

Fig. 5

problem. So far all this work has been done with odorous substances diluted to the odor vanishing point. In other words, the value of 73.3 per cent is the reduction in concentration necessary to detect consistently the "perceptibility threshold." There is also a so-called "differential threshold," a study of which has revealed a principle named after the scientist Weber* who first enunciated it. This law states that the increase (or decrease) of stimulus necessary to produce an increase (or decrease) of sensation in any of the five senses is not an absolute quantity, but depends upon the proportion which the

* "Der Tastsinn und das Gameingefuhl," in Wagner's *Handworterbuch der Physiologie*.

increase (or decrease) bears to the immediately preceding stimulus. Some of these values which have been established are: sight, 1 per cent; touch, as in lifting weights, 2.5 per cent; touch, as in response to pressure, 5 per cent; and sound, 10 per cent. The value for the sense of smell has been the most difficult to determine, owing to the large number of uncontrollable variables, but it has been thought to be in the range of 25 to 33 per cent.

In the writer's attempt to measure the "differential threshold" for smell, the following procedure was adopted. The observer was presented with a series of pairs of flasks to smell, the first pair of which would contain the same amount of odor. In the successive pairs, the difference in odor was 15, 30, 45, 60 and 75 per cent, respectively. This constituted half of one observer's test. He was then presented with the same series but in opposite order of strength. The observer was required to state whether, in each pair of flasks, the odor concentrations were apparently equal, or if unlike, which was the stronger. The concentration of odor which was maintained constant in one of the flasks throughout the test was called the base dilution. Each observer was tested four times on different occasions, using a different base dilution for each test. In all flasks in every test the odor concentration was well above the "perceptibility threshold."

Five observers were thus tested. The results secured from the smelling of about 500 flasks are summarized below:

Reduction from base dilution, %	15	30	45	60	75
Correct observations, %	42.5	47.5	65.0	76.9	97.5

These results lead to the conclusion that any concentration of odor must be reduced approximately 75 per cent before a reduction can be recognized consistently by the sense of smell. It should be noted that this value agrees very well with the figure for the "perceptibility threshold" of 73.3 per cent, previously obtained.

In conclusion, there arises the question of the present status of the threshold test, representing as it does a useful, but by no means dependable, quantitative method of determining odor in water. The procedure given in *Standard Methods* calls for dilution steps equivalent to a 50 per cent table, yielding numerical odor values of the order 1, 2, 4, 8, 16, 32, etc. By its nature the standard procedure should lead one to interpret these numerical values as being merely rough estimates of odor concentration, rather than as strictly quantitative. The more recent adoption of the method for purposes of

activated carbon evaluation, however, assumes that strictly quantitative figures are obtainable. In efforts to obtain greater accuracy, first 5 per cent and later 10 or 15 per cent dilution tables were specified. These devices do not, however, improve the basic accuracy of the test, as is clearly shown by the preceding data. Likewise, the many modifications in procedure and technique suggested and tried by the Carbon Committee have generally failed to give consistent results. We know now that a threshold value is not a fixed point, but may vary considerably, not only between individuals, but also between successive determinations by the same individual. The writers hope that their methods of accuracy measurement, both direct and indirect, may, in the future, serve as tools with which to gage the success of subsequent efforts to make the threshold test a quantitative method.

Discussion by *Douglas Feben*. The olfactory membrane is contained in a part of the nasal cavity not visited by normal respiratory air. It is a membranous patch, different in color from the surrounding tissue, and is composed of long, nucleated cells terminating in hair-like processes which are bathed in a mucous secretion. These cells are connected to the first or olfactory nerve, and the sensation produced by their reaction to stimuli is the true smell sense. This should not be confused with the sensation produced by irritants such as ammonia, chlorine, etc. These and similar substances affect a portion of the lining of the nasal cavity visited by normal respiratory air, and the nerve then involved is the tri-geminal.

Following is a description of the steps involved in the odor reaction due to presenting to the nose a flask containing a solution of an odorous substance. The amount of possible error in each of the steps described is impossible of measurement, but it should be remembered that sometimes they will tend to cancel each other out and at other times accumulate, thereby creating a wide range of error.

The extent of the smell sensation starts primarily with the concentration of the odorous substance in solution, and to be odorous it must have a vapor pressure. Particles of the odorous substance must be released into the air above the solution. The amount released will depend upon the vapor pressure of the substance, the temperature, and the amount of agitation imparted to the flask contents.

In removing the stopper from the flask and presenting it to the nose, some dilution with exterior air takes place. Then, in order for

the odor-bearing vapor to be conveyed to the olfactory membrane, the observer must "sniff." Further dilution with the exterior air now takes place, depending upon the proximity of the nose to the neck of the flask, and the intensity of the sniff. When the odor-bearing vapor reaches the olfactory membrane, the odorous particles must go into solution with the mucous secretion, and the resultant concentration will depend not only upon the amount of the odorous substance delivered up, but also upon the extent of the secretion. Reaction with the cell processes takes place, impulses are conveyed by the olfactory nerve to the brain, where the sensation is produced after being influenced by the observer's inhibitions or reflexes, conscious or otherwise. Furthermore if this sensation is to be compared qualitatively or quantitatively with a subsequent sensation, an odor memory must be retained.

It is a common fact of human experience that the five senses are prone to error whenever direct estimation is attempted. It is for this reason that we surround ourselves in the laboratory with a multitude of devices specifically designed to make these measurements for us, and to transmit the results to our consciousness through the medium of sight. The use of ocular stimuli is usually selected for the simple reason that, while subject to error, it is the most dependable of the five senses. And yet any amateur photographer appreciates the use of a photo-electric cell for measuring light intensity accurately. If an accurate analysis of light quality is desired we rely on the spectroscope.

In the analysis of sound, which is a wave vibration of the atmosphere, its quantity, or the amplitude of the wave motion, is determined accurately only by converting the energy of the wave motion into a form capable of visual rendition. The difficulty with which sound quality, or frequency, can be directly estimated is apparent in the rarity of those individuals gifted with the sense of perfect pitch.

The sense of touch can be roughly subdivided into the response to the stimulus of either pressure or heat. In the case of pressure or weight, we have devised the balance wherein a difference of perhaps 0.00005 gram in weight is converted into a 1-millimeter movement of a pointer, a visual stimulus, readily identified. The fact that our impressions of temperature are inaccurate is beyond question. If we place the left hand in 0°C. water, and the right in 50°C., and then after a short interval plunge both hands into 25°C. water, our left

hand tells us "warm" and the right hand "cold." The movement of the mercury column in a thermometer, again a visual observation, is our simplest method for securing the desired information accurately.

After all, the human senses have been evolved for the sole purpose of the protection of the individual and the perpetuation of the species. Primitive man, or for that matter, modern man, protects himself constantly during his waking hours by the use of his eyes. This sense has therefore reached the highest in his development. The use of smell was developed primarily to supplement taste as a means for discrimination between what is beneficial and what is deleterious for his nourishment, a process requiring but a small amount of the sum total of his daily efforts. In the case of lower animals with notoriously poor vision, the sense of smell is highly developed as compensation, but in man the sense of smell is anything but dependable. This has been stated tersely by Dr. Lessing,* who said: "smell is the sense least amenable to either qualitative or quantitative definition."

Discussion by *John W. Hassler*.† It is common knowledge that sensitivity to tastes and odors will vary between different individuals, and also, that the sensitivity of any individual will vary from one time to another. When the threshold test was first developed, unfortunately, many believed its procedure eliminated these factors, and that threshold numbers represented absolute values that were independent of the observer or of the time of observation. Since the pendulum originally swung too far in giving imaginary virtues to the threshold test, Hulbert and Feben have rendered a service in pulling it back. The paper, however, is so phrased that some readers may be apt to push the pendulum too far in the opposite direction by concluding that the threshold test has no practical value. The writer is quite certain that Hulbert and Feben do not intend to convey this impression, but that they are interested in preventing misuse of the threshold test. They have developed a scientific method of determining individual accuracy, and this makes it possible for any operator to use the test with full understanding of what the results mean.

* Dr. Lessing's discussion of "The Scientific Basis of Odor," read by Dr. G. M. Dyson before the London Section of the Society of Chemical Industry, April 7, 1938.

† Director of Research, Industrial Chemical Sales Division, West Virginia Pulp & Paper Co., Tyrone, Pa.

Consumer Detection of Tastes and Odors

Many water operators have, at some time or other, received consumer complaints of tastes and odors. Such complaints are handled in various ways, one of which is to consider that the trouble is imaginary or, if real, to assume that consumers will get tired of complaining. Water operators, however, usually believe that a taste and odor complaint merits consideration, and that the best way of dealing with the complaint problem is to maintain conditions that insure the delivery of a good water. Perhaps the simplest way of providing control of tastes and odors is to smell and taste the water regularly, since, after all, this is the method the consumer employs. A weakness of this technique, however, is the fact that tastes and odors may become worse so gradually that a water operator does not realize the change. Of course, the consumer is in the same position, and he, also may not notice a gradual deterioration in the quality of the water. Then, only when visitors come to town, is the poor quality recognized.

All of this difficulty can be corrected readily by making a daily comparison with odor-free water, since such a comparison immediately refreshes the memory of what a good water should be like. On this basis, a water can be described as having a "good," "bad," or "very bad" taste. Unfortunately, however, everyone does not attach the same meaning to adjectives, so the merit of the threshold test is that it substitutes numbers for adjectives. When different individuals use the terms "good" or "bad," their interpretation may vary by many hundreds or thousands of per cent. Thus, Hulbert and Feben's figure of 70 per cent average maximum error indicates a striking improvement over the use of adjectives. Accepting as correct that 70, or even 100 per cent is the average maximum error, the threshold test still has definite practical utility for the operator. After all, if the water works operator cannot tell a difference of less than 70 per cent under laboratory conditions, it follows that even a critical consumer will not detect any smaller difference. In fact, the consumer probably will not detect a difference of even 70 per cent for he must rely on his memory of how the water tasted yesterday. A critical consumer who has been satisfied with a water with a threshold number of 2 will not be apt to find fault if the number changes to 3, although he may complain if it goes much higher. On the other hand, if the consumers have been complaining about water with a threshold number of 150, we would indeed be optimistic to expect them to evince any great enthusiasm if it were reduced to 100.

Short Parallel Method of Threshold Procedure

Hulbert and Feben describe a differential odor test. One must keep in mind that there is a fundamental difference between the differential odor test and the threshold test. The differential test may be compared to holding a weight in each hand and trying to detect the difference in weight, whereas, the threshold test is comparable with having no weight in one hand and attempting to determine when a weight is placed in the other. In the realm of tastes and odors, the threshold test endeavors to compare a condition of complete absence of smell as contrasted with the faintest trace that can be detected.

Although the use of an odor-free blank constantly refreshes the memory of an odor-free water, it does not prevent one from becoming less sensitive to the odor being examined. The method employed by Hulbert and Feben is a so-called "series method," i.e., a sample of water is tested for a threshold value, then a second sample is run, etc. In this method there may be a considerable interval of time between the time the threshold number of the first sample was determined, and the time of determining the threshold number of the last sample. Meanwhile the observer's sensitivity to the odor may change. It has been found, when employing the series method, that if the total time exceeds one hour, errors are often as great or even greater than those reported by Hulbert and Feben. Moreover, if the basic data of the Hulbert and Feben paper are examined, it will be fcund that the error between the first and second samples is considerably less than 70 per cent. All of this suggests that an accuracy better than 70 per cent may be obtained by imposing rigid limits on the total time allowed for conducting threshold tests.

In the work of the writer in recent years, he has employed a method known as the "short-parallel method," which greatly reduces the time interval between the final determination of the threshold numbers of different samples. By limiting himself to an examination of three, or at the most four samples, he has found it possible to get reproducible results within an average deviation of ± 15 per cent (based on the Hulbert and Feben dilution method of determining accuracy). This short-parallel method has been used to compare the influence of different treatments on the odor quality of water. While it is true that a single 15 per cent improvement in the quality of water is not enough to be noticed by the consumer, if several 15 per cent improvements are made, the cumulative effect will result in an overall improvement great enough for the consumer to detect.

It is perhaps desirable to give a word of caution. One must not expect to make a comparison of, say, three treated samples in the afternoon and to get differences of only ±15 per cent between the threshold values of the morning and afternoon runs. Actually, the difference may run over 50 per cent. One can expect a possible ±15 per cent accuracy only within the results of any one experiment. If one experiment is compared with a later experiment, the comparison should be based on percentage improvement, and then only if there is no change in the raw water.

Measurement of Twilight Zone

Hulbert and Feben have made a valuable contribution in measuring the width of the "twilight zone," the region where the observer's sensitivity is so indefinite that he may call the same concentration "positive" at one time and "negative" the next. Their results certainly indicate that the twilight region is too wide to be used for accurate results. On the other hand, one must avoid concluding that the width of the twilight zone is, in itself, a measure of the inherent error involved in the threshold test. After all, the real question is how closely the edges or boundaries of the twilight zone can be reproduced.

Louis B. Harrison has suggested an analogy. As he points out, many indicators used in ordinary titration have a twilight zone, e.g., methyl orange, which changes in color over a wide range of pH. This does not, however, rule out the use of methyl orange. Instead it is endeavored to educate the eye to detect the point at which the indicator first starts to change color. Neither is it considered necessary to employ an acid that is strong enough to produce an unmistakable color change with a single drop. The average analyst will prefer a weaker acid even though it may result in greater differences in the number of milliliters required in check tests. So, while a knowledge of the width of the twilight zone indicates what to avoid, the knowledge also suggests the next step, i.e., to find out the accuracy with which the boundaries or edges of the twilight zone can be measured.

The writer's laboratory has not extensively used the twilight zone method, but an indirect experience is worth quoting. This experience deals with the use of the threshold test for the evaluation of carbon, a point that has, so far, been avoided because the emphasis that has been given to the use of the threshold test for the evaluation of carbon has obscured its more important uses. This experience, then, is

quoted merely to show a remarkable result that has been obtained by the twilight zone threshold method.

A sample of carbon was forwarded to C. H Spaulding. Then sometime later when he requested samples of other qualities that were available, a duplicate sample of the earlier sample was included without his knowledge of the duplication. Later, in commenting on his results, Spaulding mentioned that the particular sample was practically identical with the prior sample he had received. This, in spite of the fact that, from physical appearances, all the samples were practically identical.

Threshold Accuracy Determinations

The great value found in the Hulbert and Feben approach for determining accuracy in the threshold test is acknowledged. Since the time Hulbert and Feben first described this approach, it has been applied by the writer to tests on 307 samples of different waters covering 22 different observers. A summary of the results is shown below.

OBSERVERS	NO.	NO. OF OBSERVATIONS	PER CENT OF OBSERVATIONS WITHIN VARIOUS ERROR LIMITS*				
			<±10%	±10-19%	±20-29%	±30-39%	±40-48%
			%	%	%	%	%
Inexperienced	14	95	20.0	35.8	26.3	11.6	6.3
Cumulative Percentage			20.0	55.8	82.1	93.7	100.0
Experienced	8	212	36.8	54.3	7.5	1.4	
Cumulative Percentage			36.8	91.1	98.6	100.0	

* Errors are based on plus or minus deviation from the arithmetical mean.

It might be pointed out that the smaller errors in results are attributed to the use of the short-parallel threshold method, which gives greater accuracy than the series method when the complete test is conducted in less than one hour.

In summary the writer should like to point out that experienced operators employing a suitable short-time procedure (e.g. short-parallel method) can obtain an average accuracy approaching ±15 per cent, and this enables an operator to compare the relative effect of three or four treatments on a water. When the test is conducted over a long period of time, however, a ±15 per cent accuracy cannot be expected. Instead the variation may run over ±35 per cent.

Even though the method should allow day-to-day variations as high as 100 per cent, it is important to emphasize that this amount of variation is less than the average critical consumer will notice. Therefore, nothing in the entire discussion should discourage the water operator from making frequent threshold tests of raw and finished water. Only in this way, can he be certain that he is always providing the treatment necessary to deliver a palatable water to the consumer.

Discussion by *W. A. Helbig*.* There can hardly be any question that the threshold odor test as constituted at present is not suitable for activated carbon evaluation. I cannot, however, agree with the conclusion that the situation is hopeless because of large discrepancies in sensitivity between various observers. I do not believe that such a conclusion is warranted until another source of error of very large magnitude is first eliminated. I have done considerable work on this error—which involves contamination of the dilution water with odor substances, even at concentrations below the perception level. Such contamination can arise either through imperfect removal of odor substances from the dilution water or may be introduced through odor substances adhering to the glass in imperfectly rinsed flasks.

It is possible to demonstrate rigidly by inductive mathematical analysis, that values ranging from 300 to 10,000 may be reported on a sample by different observers, where an error of this kind is operative.

According to Hulbert and Feben, we cannot hope for consistent results in odor evaluation under any conditions. I believe that this is too pessimistic and should not be established as a conclusion until demonstrable sources of error have been dealt with.

Discussion by *Neil Kershaw*.† At the first reading of the Hulbert and Feben paper, the thought came to mind that if the mathematical average for the rating in proper order is 2.5, then this figure should be much better when aided by the sense of smell. Actual tests of four carbons on three successive times, with recoding between trials, however, gave average figures very closely resembling the 2.5 average mentioned above. In other words, these data would substantiate their claim that in all probabilities chance is the main factor. This

* Chemical Engineer, Sales Department, Darco Corp., New York City.

† Chief Chemist, Indianapolis Water Co., Indianapolis, Ind.

information likewise corroborates the Carbon Committee's findings on a standard sample of phenol-bearing water examined by the members in a co-operative study, but there too the determination was on a phenol odor in distilled water and not on natural odor-bearing water.

The twilight zone discussion appears to be logical and pertinent to the question. It indicates that the test has been extended to a point generally beyond sensitivity of the instrument used to measure it—the olfactory membrane. In other words, the dilution tables have been prepared in increments far closer than it is possible to detect consistently. This, however, is false accuracy since the sense of smell is not able to detect them with any reasonable degree of accuracy.

In Table 2 the authors have called the values "actual" and "found," whereas it appears it would have been better to have called them "theoretical" and "found." It has been suggested, as the paper points out, that hydrolysis, dissociation, or the like may cause drastic changes in the odor characteristics and, for that reason, diluted portions of an odor would give theoretical odor values but not necessarily actual values. This table is also based on a known substance diluted with distilled water and may give results quite different from substances that might occur in natural water.

Table 1 seems to be quite conclusive actually as well as mathematically. Tables 2 and 3 are likewise very conclusive mathematically, but, as it has been pointed out above, one is on a diluted sample the actual facts about which, it is probable, no one knows, and the other on a known odor in distilled water which is a condition not attainable in practice.

Feben's discussion of the olfactory membrane and its functions seem further to substantiate their claim of the unreliability of such a test to evaluate carbon. The one factor that may or may not enter into this discussion is the failure of the test to take into consideration the odor characteristic. By this is meant the possibility of like threshold values, or even greater ones, for water that is definitely less offensive from the standpoint of palatability.

In conclusion it may be said that the threshold test, observing the extending of the "twilight zone" as a limiting factor, has merit from an operation standpoint but is still questionable as a means of evaluating carbon.

Methods of Determining Fluorides

Committee Report

Outline of Committee Program

THE Committee was appointed in 1936 and instructed to make a careful study of the Elvove and Sanchis methods of determining fluorides in water, and of such other methods as appeared to hold promise. After some preliminary study and correspondence, the following program was adopted:

1. Selection by the Committee of the methods to be studied and mutual interchange of all available information with respect to each. It was agreed that to be of most value this should include actual experiences of each member with these methods and the results obtained.

2. A critical review of this material and of the literature by each committee member in order to settle upon those points needing further study.

3. The allocation of these points to individual committee members for investigation.

4. The assembling and review of all work done and the preparation of detailed directions for each procedure in a form satisfactory to all committee members.

5. The analysis, by each committee member and by as many of the selected methods as might be possible, of a number of waters of widely varying source, chemical quality and fluorine content.

6. Study and interpretation of the results obtained and preparation of final report.

7. Preparation of an essentially complete bibliography on methods of determining fluorides.

A committee report presented on June 25, 1941, at the Toronto Convention by A. P. Black, *Chairman*. Committee personnel is listed at the close of the report.

Selection and Study of Methods

The first phase of the work required considerable time and resulted in a voluminous correspondence. The material so collected was made available in 1937 in mimeographed form as the Committee's first progress report and was briefly summarized by the Chairman at the Buffalo Convention.

The second phase of the work was then undertaken and more than a year devoted to a detailed study of the methods selected. During this time, the originators of some of the methods were approached for suggestions and all those approached responded freely and generously. During this period Scott developed the technic referred to in this report as the "Sanchis B" method, but which, in view of its simplicity and demonstrated precision, should probably be designated, either as the Scott method, or as the Scott modification of the Sanchis method. Without a single exception, every laboratory represented on the Committee made significant contributions during this period.

The first drafts of directions for the various procedures, arranged in the form used in *Standard Methods*, were then prepared by the Chairman and sent to all committee members for approval. When all suggestions were in, the material was rewritten and re-submitted until all had been approved by the Committee.

Provision Against Experimental Error

Before beginning the analytical work, it seemed desirable to eliminate in advance, as far as possible, those errors which might result from impurities in chemicals, possible errors in calibration of weights and volumetric apparatus, possible changes in the fluorine content of samples upon standing, etc. Accordingly, a one-pound sample of the purest reagent grade sodium fluoride was recrystallized, dried to constant weight and analyzed in the laboratory of the Chairman. The fluorine was precipitated and weighed as strontium fluoride, following the method of Kolthoff and Stansby (1) and the sample was found to contain fluorine equivalent to 99.8 per cent sodium fluoride.

Each committee member was then sent a portion of the material together with its analysis and all stock solutions and working solutions of fluoride used during the remainder of the work were prepared in each laboratory from this material.

To a large sample of the municipal water supply of Gainesville, Fla., which contains 160 p.p.m. alkalinity as calcium carbonate and is quite

low in both sulfate and chloride, stock sodium fluoride was carefully added to represent the addition of exactly 2 p.p.m. of F^-. The results of many analyses over an extended period of time have consistently yielded a value of 0.2 p.p.m. of F^- for this water by both the Sanchis method and the method of distillation and titration. As prepared, therefore, its F^- content was very close to 2.2 p.p.m.

When all laboratories had prepared and standardized their solutions, a one-half gallon sample of this prepared water was sent to each, with the request that it be carefully analyzed as a check sample. No information as to its fluoride content was given. Every laboratory except one employed Scott's modification of the Sanchis method and most of them used one or more additional methods, reporting all values obtained. The agreement was excellent. Eight of the laboratories reported that the sample contained 2.2 p.p.m. of F^- and the other two reported that it contained 2.1 p.p.m. of F^-. It was believed, therefore, that this constituted a satisfactory check in view of the number of variables involved, and that the final phase of the work could be begun.

One other possible error to be guarded against was that the fluorine content of samples to be examined might change during shipment or upon storage for considerable periods of time in glass bottles. To check this point, each committee member was requested to divide the remainder of the Gainesville check sample into two portions and store one in a pyrex container and the other in a soft glass bottle, each to be analyzed at regular intervals as long as the samples lasted. In addition, since eight of the laboratories had, by mistake, been sent an extra gallon of water No. 21, containing 8.2 p.p.m. of F^-, this water was also used to check the possible effect of standing. Some laboratories also prepared additional waters and used a variety of glass containers. Although all laboratories made the tests over a period of 60 to 90 days and two continued them at monthly intervals for over a year, in no case were significant changes noted in the F^- content of the samples tested, all samples consistently yielding either the exact original value or within $\pm$ 0.1 p.p.m. of that value. The F^- content of waters so tested varied from 1 to 10 p.p.m.

Geographical Diversification of Sampling

In order to submit the procedures finally decided upon to the most rigorous tests, it was thought desirable to use a number of different samples collected from widely separated sources and differing greatly

in chemical character and fluorine content. Through the courtesy of Dr. H. Trendley Dean, Dental Surgeon of the U. S. Public Health Service, the Chairman was furnished with a list of states in which fluorine-bearing waters are known to occur. Letters were addressed to officials of the boards or departments of health of these states explaining the problem and requesting their co-operation. The

TABLE 1

Co-operating State Boards of Health

STATE	NAME AND TITLE OF CO-OPERATING OFFICIAL	SAMPLES TO LABORATORIES AS FOLLOWS:									
		A	B	C	D	E	F	G	H	I	J
Alabama	J. N. Baker, State Health Officer	1	1	0	0	0	1	1	1	0	0
Arkansas	Walter A. Reiman, Acting Chief Engr.	1	1	0	1	1	1	1	1	0	0
Colorado	B. V. Howe, Director, Div. of San. Eng.	2	2	2	2	0	2	0	2	2	2
Idaho	W. V. Leonard, San. Engr.	1	1	1	0	0	1	0	1	1	1
Indiana	B. A. Poole, Chief Engr. Bureau of San. Eng.	2	2	0	2	2	2	2	2	2	2
Iowa	Walter L. Bierring, Comr. of Public Health	1	1	0	1	1	1	1	1	0	0
Louisiana	John H. O'Neill, San. Engr.	1	1	0	1	0	1	0	1	0	0
Nevada	W. W. White, State San. Engr.	1	1	1	0	1	1	0	1	1	0
North Carolina	Carl V. Reynolds, State Health Officer	1	1	0	0	0	1	0	1	0	0
North Dakota	Maysil M. Williams, State Health Officer	1	1	1	1	1	1	1	1	1	1
Oklahoma	William D. Hayes, Director of Labs.	1	1	0	1	0	1	0	1	1	1
South Dakota	W. W. Towne, Director, Div. of San. Eng.	2	2	2	2	2	2	2	2	2	2
Tennessee	W. C. Williams, Comr. of Public Health	1	1	0	0	1	1	1	1	0	0
Texas	George W. Cox, State Health Officer	2	2	2	2	0	2	2	2	2	2
Utah	Lynn M. Thatcher, Director Div. Public Health Eng. & Sanit.	2	2	2	2	0	2	0	2	2	2
Virginia	I. C. Riggin, State Health Comr.	0	2	2	2	2	2	2	2	0	0
Totals		20	22	13	17	11	22	13	22	14	13

response was immediate and most gratifying. As a result, a total of 174 one-gallon samples were collected and shipped to the ten co-operating laboratories, the entire cost of collection, packing and shipping being borne by the respective boards of health. Twenty-two different waters were obtained. Table 1 gives the names and titles of the co-operating officials, the number of samples furnished by each and their distribution among the various laboratories. Table 2 shows this distribution of samples also and in addition gives the letter designation of each co-operating laboratory and the methods chosen for use by each laboratory.

TABLE 2

Assignment of Samples to Co-operating Laboratories and Methods to Be Used

LABORATORY	LAB. DESIGNATION	NUMBER OF SAMPLES AND METHODS TO BE USED								
		Sanchis Method			Elvove Method	Distillation and Titration	Distillation and Sanchis			Foster
		A	B	D			A	B	D	
Florida (Black)	A	21	21	21	21	21	21	21	21	21
U.S.G.S. (Collins)	B	22	22	22	0	0	0	0	0	22
Los Angeles (Goudey)	C	13	13	13	13	13	13	13	13	0
Kansas (Haney)	D	18	18	18	18	0	8	8	8	0
Wisconsin (Nichols)	E	12	12	0	12	0	0	0	0	10
Ohio (Scott)	F	22	22	22	0	0	0	0	0	0
Illinois (Weart)	G	14	14	14	14	0	14	14	14	0
Rubidoux (Wilcox)	H	22	22	22	0	22	22	22	22	0
Arizona (Smith)	I	14	14	0	0	14	0	0	0	0
Texas (Connell)	J	13	13	13	0	13	0	0	0	0

Standardization of Samples

Detailed directions for collecting, bottling and shipping the samples were prepared and furnished to the officials of each co-operating board of health. These directions were as follows:

"*Bottles:* It is suggested that one-gallon glass bottles be used. They should be cleaned with a mixture of warm sulfuric acid and sodium or potassium dichromate or with alkaline permanganate, followed in either case by a mixture of oxalic and sulfuric acids and *thorough* and repeated rinsings with water and draining. In the case

of new bottles, thorough washing with soap and water followed by thorough rinsing and draining will be sufficient.

"At the time of collection, each bottle should be completely filled with the water being sampled, emptied and then refilled for the final sample. Bottles should be stoppered with *new corks,* firmly wired or tied in place. An air space should be left under each cork of sufficient size to provide for expansion of water due to changes of temperature during shipment. One gallon of water, changing from 15°C. to 30°C. will undergo an expansion of about 9 ml. It is suggested that an air space of about 25 ml. should be ample.

"*Collection of Samples:* Aside from having the bottles scrupulously clean and thoroughly rinsed with the water to be sampled, the only other precaution which must be taken is to be sure that all samples are exactly the same and that all are truly representative of the supply being sampled. This point must be left to the judgment of the individual making the collection. If there is any doubt on this point, it is obvious that absolute uniformity of all samples can be assured by drawing a considerable volume of water into a carefully cleaned and rinsed tub or barrel, mixing thoroughly and then bottling the samples. It is believed that this will hardly be necessary in most cases.

"*Shipment of Samples:* Bottles of water are best shipped in wooden crates or wicker containers, well protected by means of excelsior and thick cardboard. Since many of the samples are to be shipped for long distances, it is believed that *every precaution* should be taken to prevent breakage.

"Each sample should bear a label indicating its source. These labels will not need to contain full information, but only enough to identify the samples."

Procedures for Methods Used

Procedure for ten different methods used by some or all of the different laboratories are given below. The methods selected for intensive study are presented in the form used in *Standard Methods* (2). Others are reproduced as submitted by the various laboratories using them. A number of determinations were made by still other modifications of some of the methods. Such values are indicated in the tables presenting the analyses of the individual waters and in each case an explanatory footnote will be found.

Tables 3 and 4 are self-explanatory. They were prepared and used by the Committee to simplify the preparation of synthetic waters needed for the unmodified Elvove method, and may be found useful by other workers.

TABLE 3

Preparation of Synthetic Waters

(Constituents Usually Present)

REAGENT	GRAMS PER LITER OF WORKING SOLUTION	1 ML. IN A FINAL VOLUME OF 50 ML. REPRESENTS:			
		Milli-equiv. Liter	Ion	Milli-equiv. Liter	Ion
$Ca(HCO_3)_2$	*1.00 $CaCO_3$	0.4	Ca	0.4	(HCO_3)
$CaCl_2$ (anh)	2.78	1.0	Ca	1.0	Cl
$CaCl_2 \cdot 6H_2O$	5.48	1.0	Ca	1.0	Cl
$CaSO_4$ (anh.)	0.85	0.25	Ca	0.25	(SO_4)
$Mg(HCO_3)_2$	*2.109 $MgCO_3$	1.0	Mg	1.0	(HCO_3)
$MgCl_2$ (anh.)	2.38	1.0	Mg	1.0	Cl
$MgCl_2 \cdot 6H_2O$	5.08	1.0	Mg	1.0	Cl
$MgSO_4 \cdot 7H_2O$	6.16	1.0	Mg	1.0	(SO_4)
$NaHCO_3$	4.20	1.0	Na	1.0	(HCO_3)
Na_2CO_3 (anh.)	2.65	1.0	Na	1.0	(CO_3)
NaCl	2.92	1.0	Na	1.0	Cl
Na_2SO_4 (anh.)	3.55	1.0	Na	1.0	(SO_4)
$Na_2SO_4 \cdot 10H_2O$	8.06	1.0	Na	1.0	(SO_4)
$NaNO_3$	0.43	0.1	Na	0.1	(NO_3)
KCl	3.73	1.0	K	1.0	Cl
K_2SO_4	4.36	1.0	K	1.0	(SO_4)

* Dissolved and saturated with CO_2. By passing CO_2 from a tank into suspensions of $CaCO_3$ and $MgCO_3$ in distilled water, it is possible to prepare at atmospheric pressure a solution of $Ca(HCO_3)_2$ equivalent to 1.12 grams $CaCO_3$ per liter and of $Mg(HCO_3)_2$ equivalent to about 2.9 grams of $CaCO_3$ per liter. Solutions are filtered, titrated, and adjusted as above.

I. Modified Elvove Method

The procedure for the Elvove method used by the Committee was that which appears in *Standard Methods* (2, pp. 36–38). A modification of this method, supplied by Dr. Elvove, and referred to as the "Modified Elvove Method," was also used. This modification is as follows:

"Determine the sulfate content (approximate determinations will

suffice) of the waters. Add to the fluoride standards sufficient of the stock solution of sodium sulfate to correspond to the sulfate content of one of the samples, choosing the sample the sulfate content of which is nearest to those of the greater number of the remaining samples. Run also as unknowns the distilled water to which had been added the required amounts of the stock solution of sodium sulfate to correspond to sulfate (SO_4) concentrations of 50, 100, 200, 500, and 1,000 p.p.m. respectively, in addition to sodium fluoride to each to correspond to 1 p.p.m. fluoride (F). Apply corrections for the sulfate

TABLE 4

Preparation of Synthetic Waters

(Constituents Usually Present in Very Small Amounts)

REAGENT	GRAMS PER LITER OF WORKING SOLUTION	1 ML. IN A FINAL VOLUME OF 50 ML. REPRESENTS:			
		p.p.m.	Ion	p.p.m.	Ion
Na_2SiO_3 (anh.)	1.00	7	Na	10	SiO_2
$Na_2SiO_3 \cdot 9H_2O$	2.33	7	Na	10	SiO_2
Na_2SiO_9	1.26	3	Na	10	SiO_2
(Water glass)					
$NaNO_3$	0.07	—	Na	1	(NO_3)
$AlCl_3$	0.13	1	Al_2O_3	—	Cl
$AlCl_3 \cdot 6H_2O$	0.23	1	Al_2O_3	—	Cl
*$FeSO_4$ $7H_2O$	0.25	1	Fe	10	(SO_4)
†$FeCl_3$ (anh.)	0.15	1	Fe	—	Cl
†$FeCl_3 \cdot 6H_2O$	0.25	1	Fe	—	Cl

* Stabilized with 5 ml. of conc. H_2SO_4. If freshly prepared, acid may be omitted and no allowance for addition of (SO_4) need then be made.

† Must be freshly prepared.

content of the samples on the basis of the results obtained with these sulfate controls, whenever the correction, if applied, would change the uncorrected result by as much as, or more than, 0.1 p.p.m. fluoride (F).

"The predetermined corrections for sulfate may be used in future work of the same type. Since, however, it appears that the fluoride concentration of the water and also the age of the reagent influence, to some extent, the effect of the sulfate, it appears preferable for the individual worker to determine these corrections under the conditions of his own work."

II. Colorimetric Determination of Fluorides by the Zirconium-Alizarin Method

Sanchis Method as Modified by Usage Since Publication

1. *Reagents*

1.1. *Standard sodium fluoride solution.* Dry the sample of NaF sent to all committee members for at least 2 hr. at 110°C. Prepare a stock solution containing 2.21 grams of the dried salt in 1 liter of solution at 20°C. Dilute 100 ml. of this solution to 1 liter at 20°C. (intermediate solution). Dilute 100 ml. of this intermediate solution to 1 liter at 20°C. This is the final working solution and contains 0.01 mg. of fluoride ion per milliliter.

1.2. *Indicator.* (a) Dissolve 0.17 gram of alizarin sodium sulfonate (alizarin red S) in 100 ml. of distilled water. (b) Dissolve 0.87 gram of reagent grade zirconium nitrate (crystalline) in 100 ml. of distilled water. Store both in a cool, dark closet or locker. To prepare the working solution, add 10.0 ml. of (a) to 10.0 ml. of (b) dropwise and with constant stirring, dilute to 100 ml. and allow to stand at least 12 hr. before using. Working solution should be prepared in this manner for each series of samples run.

1.3 *Hydrochloric acid 3* N. This shall be prepared by mixing exactly 258 ml. of concentrated HCl (A.C.S. reagent grade) with about the same volume of distilled water, cooling and diluting to 1 liter.

1.4 *Sulfuric acid 3* N. This shall be prepared by mixing exactly 84 ml. of concentrated H_2SO_4 (ACS reagent grade) with about 500 ml. distilled H_2O, cooling and diluting to 1 liter.

1.5. After cooling, the two acid solutions shall be mixed and labeled, "Mixed Acid Solution."

2. *Preparation of Standards*

2.1. To a series of eleven 250-ml. Erlenmeyer flasks, add 0.0, 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, and 20.0 ml. of the sodium fluoride working solution (1 ml. = 0.01 mg. of fluoride ion). Add distilled water to each flask to make all volumes 100 ml. These standards are then treated exactly as the sample in the procedure to follow.

3. *Determination*

3. A 100-ml. aliquot of the sample to be analyzed, freed from turbidity and suspended solids by filtration if necessary, is trans-

ferred to a 250-ml. Erlenmeyer flask. To each of the 100-ml. aliquots of samples thus measured, and to the prepared standards, add exactly 4.0 ml. of the "mixed acid solution," and exactly 2.0 ml. of the prepared indicator solution which has stood for 12 hr. or overnight, after mixing and diluting. For this work great care should be exercised at this point as it represents probably the greatest single chance for experimental error. Carefully selected narrow-bore pipettes or micro-burettes should be used and the pipettes or micro-burettes used for both mixed acid and indicator should be the same for all samples and standards.

3.2. Place flasks on a hot plate, bring the solutions rapidly to the boiling point and remove 5 to 10 sec. after boiling begins. Do not allow to boil vigorously or to simmer for a long time.

3.3. Four hours after cooling, or the following day, transfer the standards to properly labeled matched Nessler tubes [Exax matched tubes meeting A.P.H.A. specifications, or their equivalent, are suggested] and make up to the mark with distilled water and mix. Transfer each of the unknowns, in turn, to a matched Nessler tube, dilute to the mark, mix and compare with the standards. If a reddish precipitate appears in any of the aliquots after cooling, disperse it by whirling the contents of the flask rapidly, transfer quickly to Nessler tubes, dilute to the mark, mix and read at once. *For this work, all such cases should be noted and check determinations run.*

3.4. If the fluoride content of any sample is greater than 1.6 p.p.m., repeat with a suitable aliquot made up to 100 ml. with distilled water.

Scott Modification of the Sanchis Method (*Sanchis B*)

1. *Reagents*

1.1. *Standard sodium fluoride solution.* Same as Section 1.1 in Sanchis A method above.

1.2. Dissolve 1.0 gram of zirconium nitrate in 100 ml. of distilled water. The solution should be perfectly clear.

1.3. Dissolve 0.2 gram of alizarin red S in 100 ml. distilled water. Mix with the zirconium nitrate solution.

1.4. *2.6* N *HCl.* Dilute 235 ml. of concentrated HCl, sp.gr. 1.19, to 1 liter, cool before completing dilution.

1.5. *2.6* N H_2SO_4. Dilute 75 ml. concentrated H_2SO_4, sp.gr. 1.84, to 1 liter. Cool before completing dilution.

1.6. Mix the two acid solutions.

1.7. *Mixed acid-indicator reagent.* Transfer exactly 70 ml. of the zirconium-alizarin solution to a liter flask and make up to the mark with the mixed acid solution. Store in a refrigerator.

2. *Preparation of Standards*

2.1. To a series of eleven matched Nessler tubes, add successively 0.0, 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, and 20.0 ml. of the sodium fluoride working solution (1 ml. = 0.01 mg. fluoride ion) and make up to the mark with distilled water and mix.

3. *Determination*

3.1. To 100-ml. aliquots of samples, filtered if necessary, in matched Nessler tubes, and to the standards, add exactly 5.0 ml. of the mixed acid-indicator solution. Mix thoroughly, allow to stand for 1 hr. at room temperature and compare samples with standards.

3.2. If the fluoride content of any sample is greater than 1.8 p.p.m., dilute a suitable aliquot to 100 ml. with distilled water and repeat.

Modification of the Sanchis Method (Sanchis D)

In this modification of the Sanchis A method, the tubes *are not heated*, but are read after standing overnight.

III. Distillation and Titration Methods

1. *Reagents*

1.1. *Sodium alizarin sulfonate solution.* Prepare a 0.01 per cent solution of the indicator in distilled water.

1.2. *Standard sodium fluoride solution.* Prepared as for the Sanchis A method, (1 ml. = 0.01 mg. of fluorine).

1.3. *Thorium nitrate solution.* A 0.1 *N* solution is prepared by dissolving 17.404 grams of $Th(NO_3)_4 \cdot 12H_2O$ in water and making up to a volume of 1 liter at 20°C. A 0.01 *N* working solution is prepared by diluting 100 ml. of the stock solution to one liter at 20°C.

1.4. *Chloracetic acid buffer solution.* (a) 23.6 grams of the best obtainable grade of the crystalline acid are dissolved in distilled water and made up to a volume of 250 ml. (b) A second 23.6-gram sample is dissolved in about 100 ml. of distilled water, three drops of phenolphthalein indicator added, and the acid solution neutralized with strong sodium hydroxide solution. The volume is made up to 250 ml. with distilled water and (a) and (b) mixed to yield 500 ml. of

buffer solution which is 0.5 M to the acid and 0.5 M to the sodium salt.

1.5. *Perchloric acid, 60 per cent.* The best obtainable grade.

1.6. *Hydrochloric acid, 0.2* N.

1.7. *Sodium hydroxide, 0.2* N.

1.8. *Solution of silver sulfate.* 4.4 grams in 500 ml. of distilled water (1 ml. = 2.0 mg. of chloride ion).

1.9. *Solution of silver perchlorate.* 29.2 grams in 500 ml. distilled water (1 ml. = 20 mg. chloride ion).

1.10. *Concentrated sulfuric acid.* The best obtainable grade.

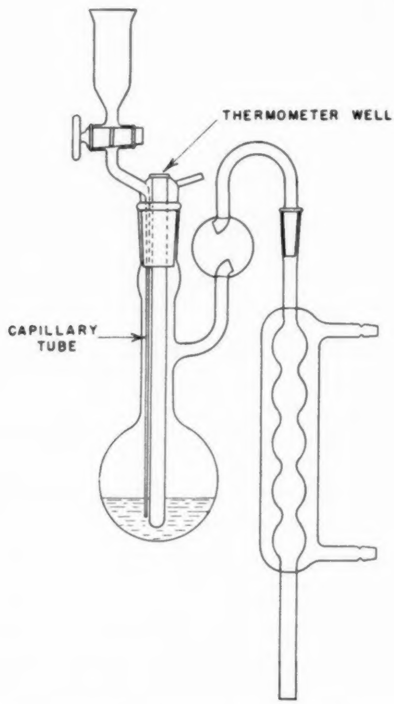

Fig. 1. Distillation Apparatus for Fluoride Determination

2. *Concentration and Distillation*

From 200 to 500 ml. of the water, depending upon the fluorine content, is made alkaline to phenolphthalein with NaOH and transferred to a separatory funnel of convenient size and evaporated to

a volume of about 15 ml. in the flask to be used for the distillation. A glass tube passing from the bottom of the distillation flask through the stopper is connected with the separatory funnel by rubber tubing. In case of waters high in $MgCl_2$ and low in alkalinity, a few drops excess NaOH should be added and the solution should remain pink to phenolphthalein during the entire concentration.

The concentrated sample is cooled, made slightly acid by the dropwise addition of 60 per cent perchloric acid, and sufficient silver perchlorate solution added to just precipitate the chlorides. A

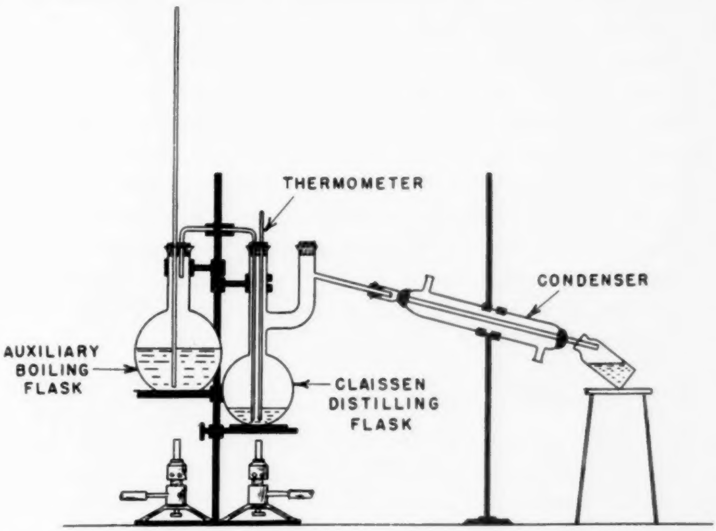

FIG. 2. Apparatus for Steam Distillation of Fluorine as Hydrofluosilic Acid

slight excess will do no harm. About a dozen glass beads are placed in the flask, 25 ml. of 60 per cent perchloric acid added and the flask fitted with thermometer and water inlet tube. The temperature is raised to 135°C. and held between 135° and 138°C. by the addition of distilled water while collecting 200 ml. of distillate at the rate of about 4 ml. per min.

The fluorine in one 100-ml. portion of the distillate is determined by the titration procedure to be described below, and the other 100-ml. portion used for a check by any desired method.

NOTE: Eberz, Lamb and Lachele (3) state that the temperature may be controlled closely during the distillation by inserting into

the water tube a capillary tube of such dimensions that it allows 4 ml. of water to flow under a water head of 35 cm. with the stopcock completely open, and enabling flow to be adjusted quickly by raising or lowering the separatory funnel containing the water. They state that distillation will often proceed for long periods without change of temperature.

In the titration procedure to follow, it has been shown by several workers that at least one source of error is a salt effect upon the indicator resulting from neutralization of acid volatilized during the distillation. Two remedies are, of course, possible: (a) The removal of chlorides before distillation by the addition of the calculated quality of silver perchlorate solution. In case sulfuric acid is preferred for the distillation, silver sulfate may be used. (b) The prevention of volatilization of sulfuric or perchloric acid as far as possible. Dahle, Wichmann and Bonnar (4) have shown that such volatilization is largely due to super-heating of the sides of the flask by hot gases from the flame and that such volatilization can be reduced to very low figures by using *small* flasks, preferably 250 ml., and fitting them *tightly and perfectly* into asbestos or Transite pads at least 8 in. square. Only that portion of the flask covered with liquid projects through the pad.

3. *Concentration and Titration*

A 100-ml. aliquot of the distillate is transferred to a platinum, or porcelain dish or pyrex beaker, the order of preference being as given, made faintly alkaline to phenolphthalein with 0.2 *N* NaOH solution and evaporated on a hot plate to a volume of about 15 ml. The solution is transferred to a 100-ml. pyrex beaker, washing the dish, if used, with several *small* portions of distilled water. The solution and washings are made just acid with 0.2 *N* HCl and made up to a volume of 25 ml. Then 25 ml. of pure ethanol and 1 ml. of 0.01 per cent solution of alizarin sodium sulfonate are added and the color adjusted to pure yellow by the careful addition of either NaOH or HCl as required. A 1-ml. portion of the chloracetic acid buffer is added and the solution titrated with 0.01 *N* thorium nitrate solution. A permanent color blank facilitates the recognition of the endpoint.

The amount of fluorine present is read from a curve which is obtained by titrating known amounts of sodium fluoride against the thorium nitrate solution by the above procedures. *For most accurate results, this curve should be constructed from data obtained by adding*

known amounts of sodium fluoride to distilled water and distilling and concentrating as above, since by so doing the unavoidable distillation blank will be canceled when the curve is used.

NOTE: *Permanent color blank:* A satisfactory color blank may be prepared by adding 5 drops of cobalt chloride and 15 drops of potassium chlorplatinate to 50 ml. of distilled water. The two solutions referred to are those prescribed for the preparation of permanent iron standards in *Standard Methods.* Eberz, Lamb and Lachele (3) recommend a color blank prepared by adding a known small volume of the thorium nitrate solution to indicator and buffer in the appropriate volume of distilled water. They performed their titrations in a volume of 30 ml. They also suggest a permanent color blank prepared from cobalt nitrate and potassium chromate solutions.

Titration without neutralization or concentration of distillate: Dahle, Bonnar and Wichmann (5) employ a back-titration procedure which does not require the concentration or neutralization of the distillate and which appears to have decided possibilities.

Reports of other investigators on this method (6–10) are cited in the reference list at the close of this paper.

IV. Ferric Thiocyanate Method

It has been found in recent work on the ferric-thiocyanate method that, although there is a slight change in reading from hour to hour after development, the differences between readings made immediately on development of the color and those made one hour later are for all practical purposes, negligible. The same is true for readings made one and two hours after development. The readings were made against standards prepared at the same time as the samples. It was also found that the one-hour and subsequent readings are more consistent than readings made immediately after development.

1. *Reagents*

1.1. *Standard fluoride solution.* 221.0 mg. sodium fluoride in 1 liter (1 ml. = 0.1 mg. F).

1.2. *Ferric chloride solution.* 75 mg. Fe as $FeCl_3$ in 1 liter containing 30 ml. *N* hydrochloric acid (1 ml. = 0.075 mg. Fe).

1.3. *Ammonium thiocyanate solution.* 24 grams ammonium thiocyanate in 1 liter.

1.4. *Nitric acid.* 0.016 *N* (equivalent to sulfuric acid used in alkalinity titration).

1.5. *Nitric acid.* 0.04 N, ($2\frac{1}{2}$ times strength of sulfuric acid used in alkalinity titration).

1.6. *Sodium chloride solution.* 82.4 grams NaCl in 1 liter (1 mg. = 50 mg. Cl).

2. *Procedure*

Measure 50 ml. of the sample of water into a comparison tube. Neutralize the alkalinity with nitric acid. Do not add an indicator, but calculate from the alkalinity titration the amount of acid necessary. If the alkalinity is low, use the more dilute nitric acid; if high, add the stronger nitric acid in order to keep the volume of the neutralized sample within 60 ml. Add 3 ml. of the sodium chloride solution (1 ml. = 50 mg. Cl). Then add 5 ml. ferric chloride solution plus the amount of ferric chloride necessary to counteract the effect of the sulfate content of the sample.

Prepare standards by adding 5 and 4 ml. of the ferric chloride solution to 50 ml. of distilled water containing 3 ml. NaCl solution (1 mg. = 50 p.p.m. Cl).

Add simultaneously to samples and to standards 10 ml. of ammonium thiocyanate solution, make the volume to 75 ml., mix well and compare after one hour. Comparison is made in a Klett (top reader) colorimeter, using 20-ml. tubes and setting the standard at zero. Fluoride in parts per million is determined from the colorimeter reading by the use of a standard reference curve.

The standard reference curves are made by plotting the results obtained by reading samples containing known amounts of fluoride (0.01, 0.02, 0.03, 0.30 mg.), prepared in the manner described above for samples against standards containing 5 ml. of ferric chloride (0.01 to 0.15 mg. F) and 4 ml. of ferric chloride (0.075 to 0.25 mg. F) and 3 ml. sodium chloride and read one hour after development.

If the fluoride content of the sample is high, the fainter color in the sample will be noticeable immediately on development. If it is markedly less than the 4-ml. standard it is advisable to take a smaller sample—adjusting the nitric acid and additional ferric chloride to be used accordingly—and making the volume up to 50 ml. with distilled water, before addition of reagents.

The reference curve for sulfate from which is read the additional amount of ferric chloride needed to counteract the effect of the sulfate in the sample is prepared by plotting the results obtained by the fading effect of samples containing known amounts of sulfate against ferric chloride standards (as in the preparation of the fluoride curves).

The readings are plotted in terms of milliliters ferric chloride. If the sulfate content of the sample is so high that more than 0.75 ml. of ferric chloride in excess of the standard amount of 5 ml. is required, a smaller sample should be taken, rather than to add a greater amount of ferric chloride.

The fading effect of chloride is less than that of sulfate and there is very little difference in the color decreases caused by 150 and 200 mg. of chloride. As 50 mg. of chloride in a 50-ml. volume is equivalent to 1,000 p.p.m. and as most ordinary waters contain less than 1,000 p.p.m. of chloride it has been found practicable to add 150 mg. of chloride ion to each sample rather than to compensate for the Cl by adding excess ferric chloride. If, however, the chloride content of the sample is more than 1,000 p.p.m., the amount of Cl added is reduced proportionately.

Nitric acid is used to neutralize the alkalinity because the effect of nitrate on the color is much less than that of either chloride or sulfate, as much as 80 mg. in the volume of sample used having no perceptible effect on the color.

As the fluoride curves overlap, it is possible, in some samples, to read the fluoride on two standards (for example, if the reading is at the upper part of the 5-ml. standard curve and the lower part of the 4-ml. standard curve), and thus to get check readings.

V. Acetylacetone Colorimetric Method Using the Photronic Colorimeter

The procedure described by Armstrong (11) has been adapted for use with the photronic colorimeter (12). Only minor changes were found necessary.

1. *Reagents*

1.1. *Iron solution.* Dissolve 1.45 grams $Fe(NO_3)_3 9H_2O$, 32.2 grams Na_2SO_4 $10H_2O$, and 1.3 ml. concentrated HNO_3 in water and make 1 liter. 5 ml. of this solution contains 1.0 mg. Fe and 1.0 mg. equivalent of SO_4 in 0.02 *N* HNO_3.

1.2. *Acetylacetone solution, 0.18 per cent in water.*

1.3. *Standard fluoride solution.* (1 ml. = 0.1 mg. of fluoride.)

1.4. *Nitric acid, approximately 1.0* N.

1.5. *Nitric acid, approximately 0.1* N.

1.6. p-*Nitrophenol indicator solution, 1 gram in 100 ml. water.*

1.7. *Sodium hydroxide, carbonate-free, approximately 0.5* N.

2. *Procedure*

Transfer an aliquot of 100 ml. of the water or an aliquot containing not more than 0.5 mg. of fluoride to a 250-ml. beaker. Add 0.1 ml. *p*-nitrophenol indicator and 1.0 *N* nitric acid until colorless and 0.5 ml. excess. Bring to a boil and allow to boil two minutes, stirring vigorously to expel carbon dioxide. Remove from the flame and cool to room temperature.

When the samples are cool, add carbonate-free 0.5 *N* sodium hydroxide until a faint yellow color of *p*-nitrophenol develops. Adjust to colorless with 0.1 *N* nitric acid, adding one drop in excess. Add 5 ml. of iron solution (1.1) and make up to 110 ml. Add 10-ml. acetylacetone solution (1.2) and mix. After ten minutes, compare in the photronic colorimeter as described above. With each set of determinations, include a sample of distilled water containing all the reagents but no fluoride. Calculate the ratio of resistance reading of the unknown to that of the fluoride-free sample and read the fluoride concentration of the unknown from curves worked out in the calibration of the instrument. Report as parts per million F^-.

VI. Texas Department of Health Method

1. *Reagents*

1.1. *Zirconium nitrate stock solution, 0.87 per cent aqueous solution.*

1.2. *Sodium alizarin sulfonate stock solution, 0.17 per cent aqueous solution.*

1.3. *Zirconium-alizarin lake reagent.* To 10 ml. of the zirconium nitrate stock solution add slowly 10 ml. of the sodium alizarin sulfonate stock solution. Dilute the mixture to 200 ml. and let stand for one day before use, but prepare a fresh lake solution every 6 to 8 days.

1.4. *Standard sodium fluoride, stock solution.* Dry a portion of pure sodium fluoride at 110°C. for two hours. Dissolve 0.221 gram of the dried sodium fluoride in one liter of distilled water.

1.5. *Standard sodium fluoride, reagent solution.* Dilute 100 ml. of the stock solution of sodium fluoride to one liter.

1.6. *Barium chloride, saturated aqueous solution,* (filtered).

1.7. *Potassium hydroxide, 6 N aqueous solution.* Prepared from C.P., A.C.S. quality potassium hydroxide.

1.8. *Hydrochloric acid, 6 N solution.* Prepared from C.P., A.C.S. quality hydrochloric acid.

2. Procedure for samples containing from 0.6 to 4.0 p.p.m. fluoride

2.1. Transfer 55 ml. of the sample to a 50-ml. Nessler tube. Add 0.5 ml. of 6 *N* HCl solution and 1 ml. of saturated barium chloride solution. If sulfate is in excess of 1,000 p.p.m. add 0.5 ml. more of barium chloride to insure complete precipitation. Mix and allow to stand 48 hr. Spin the tube on its vertical axis once or twice during the 48-hour interval to dislodge barium sulfate from the side of the tube.

2.2. Decant 51.5 ml. (equivalent to 50 ml. of the sample) of the clear supernatant sulfate-free sample into another Nessler tube.

2.3. Prepare standards containing 0.00, 0.02, 0.04, 0.06, 0.08, 0.10, 0.12, 0.14, 0.16, 0.18, 0.20, 0.24, and 0.30 mg. of fluoride. Add the standard sodium fluoride solution to 50-ml. Nessler tubes and dilute to the mark. Add 1 ml. of saturated barium chloride solution to each standard. (A modification of a procedure used in the Iowa State Water Laboratory, Iowa City, Iowa.)

2.4. Add 3.5 ml. of 6 *N* HCl to the sample, and 4 ml. to each of the standards. Mix, then add 2 ml. of the zirconium-alizarin lake reagent to the sample and to each of the standards. Mix well and after at least one hour, compare the sample with the standards over a white surface under a strong but diffused light.

3. Procedure for samples containing in excess of 4 p.p.m. fluoride

3.1. Transfer 11 ml. and 27.5 ml. of the sample to 50-ml. Nessler tubes. Dilute to 55 ml. and proceed as for samples containing 0.6 to 4.0 p.p.m. fluoride (Parts 2.1–2.4).

4. Procedure for samples containing less than 0.6 p.p.m. fluoride

4.1. Add 0.5 ml. of 6 *N* potassium hydroxide solution to 225 ml. of the sample and evaporate the sample to about 40 ml. volume. Allow the concentrated sample to cool and transfer it to a 50-ml. Nessler tube, and dilute to 55 ml.

4.2. Add 1 ml. of 6 *N* HCl and precipitate sulfates as described in Part 2.1.

4.3. Decant 51.5 ml. (equivalent to 200 ml. of sample) of the sulfate-free sample into a 50-ml. Nessler tube and proceed as in Part 2.4.

NOTE: Lamar and Seegmiller (13) have recently reported that quantities of fluoride less than about 0.4 p.p.m., which are difficult to determine by the usual methods, may be determined easily and accurately by using sulfuric acid instead of a mixture of sulfuric and hydrochloric acids or hydrochloric acid alone. It is essential that the pH be controlled accurately to obtain the maximum sensitivity.

TABLE 5

Analytical Data Obtained From Samples

Key to "Other Methods"

* Sanchis A, tubes read after 4 hr.
† Silver perchlorate-perchloric acid distillation.
‡ Foster thiocyanate method.
§ Sanchis D, tubes read after 4 hr.
‖ Elvove method, no corrections.
¶ Distillation and photronic colorimeter.
** Sanchis A, determinations made 4 mo. after first determinations.
†† Texas Department of Health method.

MINERAL ANALYSIS		LABORATORY	PARTS PER MILLION F^- BY METHOD INDICATED									
			Direct Sanchis			Distillation and Sanchis			Elvove		Distillation and Titration	Other
Constituent	p.p.m.		A	B	D	A	B	D	Orig.	Modif.		
Sample 1—Amarillo, Texas												
Total dissolved solids	449.	A	6.5	6.5	6.5		5.9				5.7	6.5*
		B	6.5	6.5	6.5							6.8‡
SiO_2 (silica)	61.	C	6.5	6.0	6.1	6.2	6.0	6.5	6.6	6.4	6.3	
Fe (iron)	0.0	D	6.5	6.4	6.3				6.6	6.5		6.8‖
Ca (calcium)	44.	E										
Mg (magnesium)	49.	F		6.5								
Na (sodium)	65.	G	7.0	9.0	7.4							6.8*
CO_3 (carbonate)	7.											6.8§
HCO_3 (bicarbonate)	376.	H										6.7¶
SO_4 (sulfate)	11.	I	6.4	6.5								
Cl (chloride)	12.	J	6.4	6.4	6.3							6.0††
NO_3 (nitrate)	3.1											
SiO_3 (silicate)	77.											
Sample 2—Bartlett, Texas												
Total dissolved solids	1,619.	A	9.0	7.7	9.0		6.2	6.3			7.5	7.6†
		B	8.0	8.0	8.0							8.0‡
SiO_2 (silica)	12.	C	8.4	8.0	8.4	8.6	8.0	8.3	8.3	7.8	7.9	
Fe (iron)	0.18	D	8.0	8.0	8.0				8.0	8.0		9.1‖
Ca (calcium)	20.	E										
Mg (magnesium)	10.	F		8.2			8.0					
Na (sodium)	555.	G	8.5	8.0	8.0							8.0*
CO_3 (carbonate)	—											8.0§
HCO_3 (bicarbonate)	473.	H									7.7	8.0¶
SO_4 (sulfate)	439.	I	8.0									
Cl (chloride)	305.	J	8.4	8.1	7.7							7.7††
NO_3 (nitrate)	3.3											
SiO_3^{--} (silicate)	15.											

TABLE 5—*Continued*

Mineral Analysis: Constituent	p.p.m.	Laboratory	Parts per million F^- by method indicated: Direct Sanchis A	Direct Sanchis B	Direct Sanchis D	Distillation and Sanchis A	Distillation and Sanchis B	Distillation and Sanchis D	Elvove Orig.	Elvove Modif.	Distillation and Titration	Other
Sample 3—Geneva, Indiana												
Total dissolved	798.	A		1.8	1.8		1.4		1.7		1.4	1.9*
solids		B	1.6	1.8	1.8							1.5‡
SiO_2 (silica)	21.	C										
Fe (iron)	1.0	D	1.8	1.8	1.8				1.8	1.7		1.8‖
Ca (calcium)	111.	E	2.3	1.9					1.8	1.8		1.7**
Mg (magnesium)	47.	F		1.7								
Na (sodium)	58.	G	1.75	1.75	1.8							1.8*
CO_3 (carbonate)	—											2.0§
HCO_3 (bicarbonate)	244.	H									1.6	
SO_4 (sulfate)	380.	I	1.6	1.7								
Cl (chloride)	12.	J	1.8	1.8	1.8							1.4††
NO_3 (nitrate)	—											
SiO_3 (silicate)	—											
Sample 4—Vanburen, Indiana												
Total dissolved	755.	A	0.7	0.7	0.7		0.7				0.6	0.7*
solids		B	0.8	0.7	0.9							0.9‡
SiO_2 (silica)	16.	C										
Fe (iron)	1.7	D	0.7	0.8	0.8				0.8	0.8		0.9‖
Ca (calcium)	115.	E	1.6	0.9					1.2	0.9		0.9**
Mg (magnesium)	48.	F		0.7			0.8					
Na (sodium)	52.	G	0.7	0.7	0.8							0.7*
CO_3 (carbonate)	—											0.7§
HCO_3 (bicarbonate)	493.	H									0.6	0.8¶
SO_4 (sulfate)	48.	I	0.6	0.7								
Cl (chloride)	138.	J	0.7	0.6	0.7							0.8††
NO_3 (nitrate)	0.											
SiO_3^{--} (silicate)	—											
Sample 5—Grimes, Iowa												
Total dissolved	1,453.	A	6.5	6.3	6.5		5.7	5.7	5.8		6.0	6.5*
solids		B	6.5	6.2	6.5							6.3‡
SiO_2 (silica)	10.	C										
Fe (iron)	1.8	D	6.3	6.2	6.3				6.0	6.0		7.3‖
Ca (calcium)	43.	E	6.9	6.4					6.2	5.9		6.7**
Mg (magnesium)	17.	F		6.4								
Na (sodium)	480.	G	6.4	6.4	6.8							6.4*
CO_3 (carbonate)	—											8.0§
HCO_3 (bicarbonate)	461.	H									5.9	6.0¶
SO_4 (sulfate)	618.	I										
Cl (chloride)	87.	J										
NO_3 (nitrate)	0.											
SiO_3^{--} (silicate)	—											

NOTE: For explanation of symbols see *Key* at head of table.

TABLE 5—*Continued*

MINERAL ANALYSIS		LABORATORY	PARTS PER MILLION F^- BY METHOD INDICATED									
			Direct Sanchis			Distillation and Sanchis			Elvove		Distillation and Titration	Other
Constituent	p.p.m.		A	B	D	A	B	D	Orig.	Modif.		
Sample 6—Reno, Nevada												
Total dissolved solids	—	A	3.4	3.6	3.5		3.6	4.0			4.0	3.4*
		B	3.8	3.8	4.0							3.9‡
SiO_2 (silica)	60.	C	3.7	3.5	3.4	3.5	3.7	3.7	4.3	3.8	3.7	
Fe (iron)	0.0	D										
Ca (calcium)	13.	E	3.8	3.9					4.0	3.9		4.2**
Mg (magnesium)	4.	F										
Na (sodium)	95.	G										
CO_3 (carbonate)	5.	H									3.3	3.6¶
$CaCO_3$ (bicarbonate)	187.	I	3.6									
SO_4 (sulfate)	61.	J										
Cl (chloride)	26.											
NO_3 (nitrate)	0.35											
SiO_3 (silicate)	—											
Al (aluminum)	0.00											
PO_4 (phosphate)	0.06											
Sample 7—Lexington, Tennessee												
Total dissolved solids	389.	A	2.6	2.7	2.8		2.6		2.8		2.9	2.7*
		B	2.7	2.6	2.9							2.7‡
SiO_2 (silica)	15.											2.5‡
Fe (iron)	0.42	C										
Ca (calcium)	32.	D										
Mg (magnesium)	13.	E	2.9	2.8					2.7	2.7		2.7**
Na (sodium)	97.	F		2.6			2.6					
CO_3 (carbonate)	0.0	G	2.6	3.0	2.8							2.6*
HCO_3 (bicarbonate)	203.											3.2§
SO_4 (sulfate)	42.	H									2.7	2.7¶
Cl (chloride)	89.	I										
NO_3 (nitrate)	1.2	J										
SiO_3^{--} (silicate)	—											
Total hardness as $CaCO_3$	133.											
Sample 8—Barbour County, Alabama												
Total dissolved solids	149.	A	0.2	0.1	0.2		0.05				0.08	0.2*
		B	0.0	0.0	0.0							0.0‡
SiO_2 (silica)	36.	C										
Fe (iron)	6.	D										
Ca (calcium)	4.8	E										
Mg (magnesium)	4.8	F		0.05								
Na (sodium)	8.4	G	0.1	0.1	0.1							0.1*
CO_3 (carbonate)	—											0.1§
HCO_3 (bicarbonate)	11.	H									0.4	0.6¶
SO_4 (sulfate)	0.	I										
Cl (chloride)	31.	J										
NO_3 (nitrate)	5.											
SiO_3^{--} (silicate)	—											
Loss on ignition	90.											

NOTE: For explanation of symbols see *Key* at head of table.

TABLE 5—*Continued*

Mineral Analysis: Constituent	p.p.m.	Laboratory	Direct Sanchis A	Direct Sanchis B	Direct Sanchis D	Distillation and Sanchis A	Distillation and Sanchis B	Distillation and Sanchis D	Elvove Orig.	Elvove Modif.	Distillation and Titration	Other
			Parts per million F^- by method indicated									
Sample 9—Beaver County, Utah												
Total dissolved sol-	—	A	3.6	3.5	3.6		3.0	3.4			2.9	4.2*
ids		B	3.9	3.6	3.2							3.4‡
SiO_2 (silica)	75.	C	3.3	3.8	3.3	3.7	3.7	3.6	3.3	3.3	3.7	
Fe (iron)	0.	D	3.6	3.6	3.6				3.2	3.2		3.6‖
Ca (calcium)	128.	E										
Mg (magnesium)	81.	F		3.5								
Na (sodium)	226.	G										
CO_3 (carbonate)	0.	H										
HCO_3 (bicarbonate)	900.	I	3.5									
SO_4 (sulfate)	197.	J	3.6	3.3	3.3							2.9††
Cl (chloride)	106.											
NO_3 (nitrate)	0.08											
SiO_3^{--} (silicate)	—											
Al (aluminum)	0.10											
PO_4 (phosphate)	0.08											
$K \times 10^5$ (specific electrical conductance)	191.0											
Sample 10—Uintah County, Utah												
Total dissolved sol-	—	A	4.4	4.4	4.4		4.4		4.4		4.2	4.4*
ids		B	4.6	4.4	4.4							4.4‡
SiO_2 (silica)	20.	C	4.7	4.5	4.6	4.8	4.5	4.5	4.5	4.6	4.5	
Fe (iron)	0.3	D	4.5	4.5	4.3				4.5	4.3		5.0‖
Ca (calcium)	1.	E										
Mg (magnesium)	4.	F		4.4								
Na (sodium)	575.	G										
CO_3 (carbonate)	153.	H										
HCO_3 (bicarbonate)	713.	I	4.4									
SO_4 (sulfate)	514.											
Cl (chloride)	41.	J	4.5	4.3	4.3							6.6††
NO_3 (nitrate)	0.08											
SiO_3 (silicate)	—											
Al (aluminum)	0.00											
PO_4 (phosphate)	0.20											
Sample 11—Bunkie, Louisiana												
Total dissolved sol-	1,050.	A	7.0	6.5	7.2		6.4	5.8			6.3	8.0*
ids		B	7.2	6.2	7.2							6.9‡
SiO_2 (silica)	6.3	C										
Fe (iron)	0.10	D	7.0	7.0	6.9				6.9	6.8		6.9‖
Ca (calcium)	3.3	E										
Mg (magnesium)	1.2	F		6.4								
Na (sodium)	413.	G										
CO_3 (carbonate)	12.	H									6.9	6.3¶
HCO_3 (bicarbonate)	739.											
SO_4 (sulfate)	0.8	J										
Cl (chloride)	194.											
NO_3 (nitrate)	0.27											
SiO_3^{--} (silicate)	8.0											
SiO_2 calculated to SiO_3^{--}	—											

NOTE: For explanation of symbols see *Key* at head of table.

TABLE 5—*Continued*

MINERAL ANALYSIS		LABORATORY	PARTS PER MILLION F⁻ BY METHOD INDICATED									
			Direct Sanchis			Distillation and Sanchis			Elvove		Distillation and Titration	Other
Constituent	p.p.m.		A	B	D	A	B	D	Orig.	Modif.		
Sample 12—Grafton, North Dakota												
Total dissolved solids	4,730.	A										
		B	3.6	3.8	3.6							3.7‡
SiO_2 (silica)	16.	C										
Fe (iron)	0.7	D										
Ca (calcium)	43.	E	4.1	3.7					3.7	3.4		3.5**
Mg (magnesium)	24.	F										
Na (sodium)	1,752.	G										
Fl (fluoride)	3.6	H										
Cl (chloride)	1,848.	I										
SO_4 (sulfate)	605.	J										
HCO_3 (bicarbonate)	923.											
Mn (manganese)	0.											
Zn (zinc)	0.2											
NO_3 (nitrate)	18.											
Total alkalinity as $CaCO_3$	756.											
Total hardness as $CaCO_3$	208.											
Al_2O_3	20.											
Sample 13—Britton, South Dakota												
Total dissolved solids	2,541.	A	7.5	6.8	7.5		6.0	6.3			5.9	7.5*
		B	8.0	8.5	7.0							
SiO_2 (silica)	6.6	C	7.8	7.3	7.5	6.9	6.8	7.2	6.7	6.5	6.9	
Fe (iron)	0.17	D	7.0	7.0	7.0				7.0	6.9		8.0‖
Ca (calcium)	20.	E	7.3	7.1					6.7	6.6		7.2**
Mg (magnesium)	5.4	F		7.1								
Na (sodium)	857.	G	7.6	6.8	7.6							7.2*
CO_3 (carbonate)	4.8											8.0§
HCO_3 (bicarbonate)	329.	H									6.9	7.0¶
SO_4 (sulfate)	1,130.	I	7.0									
Cl (chloride)	335.	J	7.3	7.0	6.8							6.0††
NO_3 (nitrate)	0.22											
SiO_3^{--} (silicate)	8.4											
Al (aluminum)	0.0											
Sample 14—Plankington, South Dakota												
Total dissolved solids	1,806.	A		1.6			1.4				1.5	
		B	1.8	1.6	1.8							
SiO_2 (silica)	9.	C	1.8	1.7	1.7	1.9	1.7	1.8		1.6	1.6	
Fe (iron)	0.6	D										
Ca (calcium)	33.	E	1.8	1.7					1.6	1.5		1.8*
Mg (magnesium)	14.	F		1.7								
Na + K (calc.)	568.	G	1.7	1.6	1.8							1.7*
HCO_3 (bicarbonate)	517.											1.8§
SO_4 (sulfate)	838.	H									1.5	1.6¶
Cl (chloride)	55.	I	1.6	1.6								
F^- (fluoride)	1.5	J	1.7	1.6	1.6							
M.O. alkalinity	424.											
Total hardness as $CaCO_3$	142.											

NOTE: For explanation of symbols see *Key* at head of table.

TABLE 5—*Continued*

MINERAL ANALYSIS		LABORATORY	PARTS PER MILLION F^- BY METHOD INDICATED									
			Direct Sanchis			Distillation and Sanchis			Elvove		Distillation and Titration	Other
Constituent	p.p.m.		A	B	D	A	B	D	Orig.	Modif.		
Sample 15—Bluejacket, Oklahoma												
Total dissolved sol-	573.	A	3.8	3.6	3.6		3.6	3.5	3.6		3.6	4.3*
ids		B	3.6	3.9	3.6							3.8‡
SiO_2 (silica)	4.8	C										
Fe (iron)	0.05	D	3.7	3.7	3.7				3.6	3.6		3.7‖
Ca (calcium)	21.	E										
Mg (magnesium)	9.8	F		3.8								
Na (sodium)	185.	G										
CO_3 (carbonate)	12.	H									3.7	3.8¶
HCO_3 (bicarbonate)	181.	I	3.6	3.6								
SO_4 (sulfate)	37.	J	3.8	3.6	3.6							3.6††
Cl (chloride)	198.											
NO_3 (nitrate)	3.3											
SiO_3^{--} (silicate)	6.1											
Al (aluminum)	0.07											
Sample 16—King Hill, Idaho												
Total dissolved sol-	—	A		14.7							13.3	
ids		B	14.	15.	14.							16.‡
SiO_2 (silica)	55.	C	14.	14.	14.	15.	15.	14.	15.	15.	14.8	
Fe (iron)	0.0	D										
Ca (calcium)	6.	E										
Mg (magnesium)	1.	F		14.5								
Na (sodium)	114.	G										
CO_3 (carbonate)	69.	H									14.4	14.8¶
HCO_3 (bicarbonate)	254.	I	14.0	14.0								
SO_4 (sulfate)	0.	J	14.3	14.1	14.7							14.0††
Cl (chloride)	7.											
NO_3 (nitrate)	0.00											
SiO_3^{--} (silicate)	—											
Al (aluminum)	0.01											
PO_4 (phosphate)	0.03											
$K \times 10^5$ (specific electrical conductance)	51.8											
Sample 17—Bauxite, Arkansas												
Total dissolved sol-	953.	A	14.	13.5	14.		12.8	14.3	14.		14.	14.*
ids		B	17.	14.	14.							14.‡
SiO_2 (silica)	14.	C										
Fe (iron)	0.25	D	14.	14.	14.				14.	14.		14.‖
Ca (calcium)	34.	E	14.8	14.3					14.0	14.3		14.6**
Mg (magnesium)	9.8	F		14.2			14.0					
Na (sodium)	323.	G	13.0	14.0	15.0							13.0*
CO_3 (carbonate)	0.0											17.0§
HCO_3 (bicarbonate)	242.	H									14.1	15.6¶
SO_4 (sulfate)	37.	I										
Cl (chloride)	388.	J										
NO_3 (nitrate)	0.91											
SiO_3^{--} (silicate)	—											
Total hardness as $CaCO_3$	125.											

NOTE: For explanation of symbols see *Key* at head of table.

TABLE 5—*Continued*

MINERAL ANALYSIS: Constituent	p.p.m.	LABORATORY	PARTS PER MILLION F^- BY METHOD INDICATED: Direct Sanchis A	Direct Sanchis B	Direct Sanchis D	Distillation and Sanchis A	Distillation and Sanchis B	Distillation and Sanchis D	Elvove Orig.	Elvove Modif.	Distillation and Titration	Other
Sample 18—Gurdon, Arkansas												
Total dissolved solids	822.	A	3.0	3.0	2.8		3.0		2.9		2.9	2.7*
		B	3.4	2.3	2.4							2.6‡
SiO_2 (silica)	14.	C										
Fe (iron)	0.08	D	2.9	2.9	2.9				2.8	2.9		3.0‖
Ca (calcium)	4.4	E	3.3	3.1					3.0	3.1		3.0**
Mg (magnesium)	1.0	F		2.9								
Na (sodium)	314.	G	3.0	2.8	3.4							3.0*
CO_3 (carbonate)	14.											3.4§
HCO_3 (bicarbonate)	360.	H									2.9	2.3¶
SO_4 (sulfate)	44.	I										
Cl (chloride)	231.	J										
NO_3 (nitrate)	0.27											
SiO_3^{--} (silicate)	—											
Total hardness as $CaCO_3$	15.											
Sample 19—Franklin, Virginia												
Total dissolved solids	289.	A										
		B	6.0	5.5	6.2							6.2‡
SiO_2 (silica)	24.	C	5.6	6.0	5.6	5.7	5.8	5.8	5.3	5.6	6.3	
Fe (iron)	0.06	D	5.7	5.6	5.7				6.0	6.0		6.1‖
Ca (calcium)	1.2	E	6.2	5.5					5.9	5.7		5.9**
Mg (magnesium)	0.6	F		5.4								
Na (sodium)	110.	G	6.4	6.0	6.0							6.4*
CO_3 (carbonate)	0.0											6.8§
HCO_3 (bicarbonate)	259.	H									5.5	6.8¶
SO_4 (sulfate)	6.6	I										
Cl (chloride)	5.6	J										
NO_3 (nitrate)	0.35											
SiO_3 (silicate)	—											
Total hardness as $CaCO_3$	5.5											
Sample 20—Gloucester, Virginia												
Total dissolved solids	1,365.	A										
		B	2.2	2.1	2.3							2.4‡
SiO_2 (silica)	17.	C	2.1	2.3	2.2	2.5	2.5	2.3	2.4	2.3	2.5	
Fe (iron)	0.24	D	2.2	2.1	2.2				2.3	2.2		2.5‖
Ca (calcium)	5.4	E	2.3	2.1					2.2	2.4		2.3**
Mg (magnesium)	2.1	F		2.2								
Na (sodium)	535.	G	2.5	2.1	2.4							2.2*
CO_3 (carbonate)	24.											2.6§
HCO_3 (bicarbonate)	722.	H									2.2	2.2¶
SO_4 (sulfate)	61.	I										
Cl (chloride)	342.	J										
NO_3 (nitrate)	1.1											
SiO_3^{--} (silicate)	—											
Total hardness as $CaCO_3$	22.											

NOTE: For explanation of symbols see *Key* at head of table.

TABLE 5—*Concluded*

MINERAL ANALYSIS		LABORATORY	PARTS PER MILLION F^- BY METHOD INDICATED									
			Direct Sanchis			Distillation and Sanchis			Elvove		Distillation and Titration	Other
Constituent	p.p.m.		A	B	D	A	B	D	Orig.	Modif.		
Sample 21—Climax Molybdenum Mine, Climax, Colorado												
Total dissolved solids	—	A	9.0	7.8	8.7		7.8	8.0	8.2		7.7	9.0*
		B	7.7	8.0	8.0							7.5‡
SiO_2 (silica)	7.	C	8.2	8.3	8.3	8.0	7.9	8.0	8.4	8.6	8.2	
Fe (iron)	0.0	D	8.0	8.2	8.2				8.1	8.0		8.8‖
Ca (calcium)	16.	E										
Mg (magnesium)	10.	F		8.3								
Na (sodium)	41.	G										
CO_3 (carbonate)	50.	H									8.7	8.9¶
HCO_3 (bicarbonate)	46.	I	8.0	8.0								
SO_4 (sulfate)	95.	J	8.2	8.1	8.0							7.5††
Cl (chloride)	5.											
NO_3 (nitrate)	0.00											
SiO_3 (silicate)	—											
Al (aluminum)	0.25											
Sample 22—Colorado Springs, Colorado												
Total dissolved solids	—	A	3.0	2.7	2.8		2.7		2.7		2.5	2.8*
		B	2.8	2.7	2.7							2.8‡
SiO_2 (silica)	12.	C	2.7	2.5	2.6	2.5	2.4	2.6	2.7	2.6	2.6	
Fe (iron)	0.4	D	2.7	2.7	2.7				2.6	2.6		2.6‖
Ca (calcium)	6.	E										
Mg (magnesium)	1.	F		2.7			2.7					
Na (sodium)	2.	G										
CO_3 (carbonate)	—	H									2.9	3.2¶
HCO_3 (bicarbonate)	20.	I	2.8	2.8								
SO_4 (sulfate)	5.	J	2.8	2.8	2.7							2.5††
Cl (chloride)	1.											
NO_3 (nitrate)	0.40											
SiO_3^{--} (silicate)	—											

NOTE: For explanation of symbols see *Key* at head of table.

TABLE 6

Averages of Results Obtained by All Methods Studied

(Numbers in parenthesis give number of determinations by each method)

SAMPLE NO.	TOTAL NO. OF ACCEPTABLE VALUES	ROUNDED MEAN VALUE	PARTS PER MILLION F^- BY METHOD INDICATED									
			Direct Sanchis			Distillation and Sanchis			Elvove		Distillation and Titration	Other
			A	B	D	A	B	D	Orig.	Modif.		
1	38	6.5	(7) 6.5	(7) 6.5	(5) 6.3	(1) 6.2	(2) 6.0	(1) 6.5	(2) 6.6	(2) 6.5	(2) 6.3	(7) 6.5
2	35	8.0	(6) 8.2	(7) 8.0	(5) 8.0	(1) 8.6	(2) 8.0	(1) 8.3	(2) 8.1	(2) 7.9	(3) 7.7	(6) 7.9
3	33	1.7	(6) 1.7	(8) 1.8	(5) 1.8		(1) 1.4		(3) 1.8	(2) 1.8	(2) 1.5	(7) 1.7
4	34	0.75	(6) 0.7	(8) 0.7	(5) 0.8		(2) 0.8		(1) 0.8	(2) 0.8	(2) 0.6	(8) 0.8
5	30	6.3	(5) 6.5	(6) 6.3	(4) 6.5		(2) 5.9	(1) 5.7	(3) 6.0	(2) 6.0	(2) 6.0	(5) 6.4
6	28	3.7	(5) 3.7	(4) 3.7	(3) 3.6	(1) 3.5	(2) 3.6	(2) 3.8	(2) 4.1	(2) 3.8	(3) 3.6	(4) 3.8
7	25	2.7	(4) 2.7	(5) 2.7	(3) 2.8		(2) 2.6		(2) 2.7	(1) 2.7	(2) 2.8	(7) 2.7
8	17	0.10	(3) 0.10	(4) 0.06	(3) 0.10		(1) 0.05				(1) 0.08	(4) 0.10
9	32	3.5	(6) 3.6	(6) 3.6	(5) 3.4	(1) 3.7	(2) 3.4	(2) 3.5	(2) 3.3	(2) 3.3	(2) 3.3	(4) 3.5
10	30	4.4	(6) 4.5	(6) 4.4	(5) 4.4	(1) 4.8	(2) 4.4	(1) 4.5	(3) 4.5	(2) 4.5	(2) 4.4	(4) 4.4
11	20	6.8	(3) 7.0	(4) 6.5	(3) 7.1		(1) 6.4		(1) 6.9	(1) 6.8	(2) 6.6	(3) 6.7

TABLE 6—*Concluded*

SAMPLE NO.	TOTAL NO. OF ACCEPTABLE VALUES	ROUNDED MEAN VALUE	PARTS PER MILLION F^- BY METHOD INDICATED									
			Direct Sanchis			Distillation and Sanchis			Elvove		Distillation and Titration	Other
			A	B	D	A	B	D	Orig.	Modif.		
12	9	3.7	(2) 3.8	(2) 3.8	(1) 3.6				(1) 3.7	(1) 3.4		(2) 3.6
13	43	7.1	(8) 7.4	(7) 7.0	(6) 7.2	(1) 6.9	(2) 6.4	(2) 6.7	(3) 6.8	(3) 6.7	(2) 6.9	(7) 7.3
14	31	1.7	(6) 1.7	(8) 1.6	(4) 1.7	(1) 1.9	(2) 1.5	(1) 1.8	(1) 1.6	(2) 1.6	(3) 1.5	(4) 1.7
15	26	3.7	(5) 3.7	(6) 3.7	(4) 3.6		(1) 3.6	(1) 3.5	(2) 3.6	(1) 3.6	(2) 3.6	(4) 3.7
16	24	14.0	(4) 14.4	(6) 14.2	(3) 15.0	(1) 15.0	(1) 15.0	(1) 14.0	(1) 15.0	(1) 15.0	(3) 14.2	(2) 14.4
17	30	14.0	(4) 14.0	(6) 14.0	(4) 14.2		(2) 13.4	(1) 14.3	(3) 14.0	(2) 14.1	(2) 14.0	(6) 14.2
18	30	2.9	(5) 3.1	(5) 3.0	(2) 3.0		(1) 3.0		(3) 2.9	(2) 3.0	(2) 2.9	(6) 3.0
19	32	5.9	(5) 6.0	(6) 5.7	(4) 5.9	(1) 5.7	(1) 5.8	(1) 5.8	(3) 5.7	(3) 5.8	(2) 5.9	(4) 6.1
20	32	2.3	(5) 2.2	(6) 2.1	(4) 2.3	(1) 2.5	(1) 2.5	(1) 2.3	(3) 2.3	(3) 2.3	(2) 2.3	(6) 2.4
21	36	8.2	(6) 8.2	(7) 8.1	(5) 8.2	(1) 8.0	(2) 7.9	(2) 8.0	(3) 8.2	(2) 8.3	(3) 8.2	(5) 8.3
22	35	2.7	(6) 2.8	(7) 2.7	(5) 2.7	(1) 2.5	(3) 2.6	(1) 2.6	(3) 2.7	(2) 2.6	(3) 2.7	(5) 2.8

Analytical Data

In Table 5 are presented, as Samples 1–22 inclusive, the data obtained from the analysis of each individual water. Mineral analyses of six of the samples were made in Laboratory C under the direction of Goudey, five in Laboratory B under the direction of Collins, five in Laboratory D under the direction of Haney and four in Laboratory G under the direction of Weart. (Tables 5 and 6 on preceding pages.)

The mineral analysis of Sample 12 is taken from Geological Bulletin No. 11 of the State of North Dakota, "Municipal Ground Water Supplies of North Dakota" and furnished to the committee by Dr. Maysil M. Williams, State Health Officer. The mineral analysis of Sample 14 was made by the South Dakota State Chemical Laboratory and furnished to the committee by W. W. Towne, Director of the Division of Sanitary Engineering of the State Board of Health.

Discussion of Data

A total of 638 values were obtained for the 22 samples. In the case of two samples, Nos. 2 and 13, 40 or more values are reported. Thirty or more values are reported for each of thirteen additional samples and there is only one sample, No. 12, for which less than 20 values are given. Through a misunderstanding, this sample was sent to only two of the ten laboratories.

Table 6 presents a condensed summary of the results. It gives the total number of acceptable values for each sample, the rounded mean of these values, the number of values obtained by each method (figures in parenthesis) and immediately below them, the mean of the indicated number of values by the particular method.

Overall Precision of Data

Table 7 presents the results of a study of the overall precision obtained, expressed in several different ways. All acceptable values, by all methods used with each individual sample, have been used in calculating the precision of the results obtained for that sample. Before considering these data, a word of explanation is in order.

As a starting point, the mean of all values for a given sample was calculated. This was considered to be the preliminary or "trial mean" only. The sum of the deviations of the individual values from the "trial mean," their signs being disregarded, was then divided by the total number of values for the sample to give the "trial mean devi-

ation." Those values whose deviations from the "trial mean" were more than four times the "trial mean deviation" were rejected. Final values for the mean and for the average deviation of a single observation, or mean deviation, were then calculated, using only the acceptable values remaining.

TABLE 7

Precision of Results Obtained

SAMPLE NO.	VALUES RETAINED	MEAN VALUE—F^-	ROUNDED MEAN—F^-	MEAN DEVIATION—F^-		AVERAGE DEVIATION ARITHMETICAL MEAN—F^-		MEAN ERROR SINGLE OBS.—F^-	PROBABLE ERROR SINGLE OBS.—F^-	MEAN ERROR ARITH. MEAN—F^-	PROBABLE ERROR ARITH. MEAN—F^-
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.th.*	*p.p.m.*	*p.p.th.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	38	6.45	6.5	0.21	32	0.034	5.3	0.31	0.22	0.050	0.035
2	35	8.02	8.0	0.14	18	0.024	3.0	0.23	0.15	0.038	0.026
3	33	1.73	1.7	0.11	65	0.019	11.	0.14	0.094	0.024	0.016
4	34	0.75	0.75	0.080	107	0.049	65.	0.29	0.19	0.050	0.033
5	30	6.26	6.3	0.24	38	0.044	7.0	0.30	0.20	0.053	0.035
6	28	3.73	3.7	0.20	54	0.038	10.	0.25	0.17	0.047	0.032
7	25	2.72	2.7	0.090	33	0.018	6.7	0.12	0.080	0.024	0.016
8	17	0.10	0.10	0.072	700	0.017	170.	0.10	0.067	0.024	0.016
9	32	3.46	3.5	0.21	60	0.037	11.	0.28	0.19	0.050	0.033
10	30	4.45	4.4	0.093	21	0.017	3.9	0.14	0.093	0.026	0.017
11	20	6.79	6.8	0.36	53	0.080	12.	0.46	0.31	0.10	0.067
12	9	3.68	3.7	0.13	35	0.043	12.	0.19	0.13	0.063	0.042
13	43	7.09	7.1	0.42	59	0.064	9.0	0.53	0.35	0.081	0.054
14	31	1.68	1.7	0.090	53	0.016	9.4	0.12	0.080	0.022	0.015
15	26	3.67	3.7	0.090	24	0.018	4.9	0.10	0.067	0.020	0.013
16	24	14.4	14.0	0.48*	33	0.10	6.9	0.77	0.52	0.16	0.11
17	30	14.0	14.0	0.30	21	0.053	3.8	0.53	0.36	0.097	0.065
18	30	2.92	2.9	0.19	66	0.035	12.	0.27	0.18	0.049	0.033
19	32	5.91	5.9	0.29	50	0.052	8.8	0.36	0.24	0.064	0.043
20	32	2.29	2.3	0.12	50	0.020	8.7	0.14	0.093	0.025	0.017
21	36	8.17	8.2	0.29	36	0.048	5.9	0.38	0.25	0.063	0.042
22	35	2.69	2.7	0.089	33	0.015	5.5	0.12	0.080	0.020	0.013

* Uncorrected mean deviation = 0.50.

It is interesting to note that there is only one sample, No. 17, for which the final mean value differs by as much as 0.1 p.p.m. F^- from the "trial mean" because of the rejection of unacceptable values. In the case of this sample, the "trial mean" of all 32 values yields a figure of 14.23 p.p.m. F^-. Rejecting two values of 17.0 p.p.m., a final

mean of 14.05 p.p.m. (rounded to 14.0 p.p.m.) is derived for the remaining 30 values. Inspection of the data for this sample reveals the fact that 17, or 57 per cent, of the 30 acceptable values are reported as exactly 14.0 p.p.m.

Of a total of 638 values reported for all 22 samples, only 20, or 3.1 per cent have been rejected, 5 of these values for one sample, No. 2. Two values have been rejected for each of four samples and one value for each of seven samples. There are ten samples for which no values have been rejected on the above basis.

When it is considered that ten different laboratories participated in the work; that no committee member, including the Chairman, had any information relative even to the approximate fluorine content of the samples; that a total of 17 different methods or modifications of methods were employed; that, in general, the personal equation is relatively high in the case of most colorimetric work; and that the samples used represent several extremes in various criteria of both chemical quality and fluorine content, it is believed that the small number of values rejected is of significance in any final evaluation of the work presented.

When accidental errors follow the "Law of Chance," it is customary to assume that the arithmetical mean is the best representative value of a series of equally trustworthy observations. The accidental error that attaches to the value of the arithmetical mean is termed the "average deviation of the arithmetical mean" and is obtained by dividing the mean deviation by the square root of the total number of acceptable values:

$$\text{Average deviation of arithmetical mean} = \frac{a.d.}{\sqrt{N}}$$

Two other measures of accidental error, however, may be employed. The first is termed the "mean error of a single observation." It may be defined as that error whose square is the mean of the squares of the differences between the observed values and the arithmetical mean:

$$\text{Mean error of a single observation} = \sqrt{\frac{d_1^2 + d_2^2 + \cdots d_n^2}{N}}$$

The other is the "probable error of a single observation." By the term "probable error" is meant, not the error most likely to occur, but a quantity of such magnitude that, in a given series of observations,

it will be equally probable that there will be the same number of errors less than it, as there are those greater than it, the errors being arranged in order of magnitude without regard to sign.

Probable error of a single observation

$$= 0.6745 \sqrt{\frac{d_1^2 + d_2^2 + \cdots d_n^2}{N - 1}}$$

The measure of uncertainty of the mean may also be calculated in two ways. The measure of uncertainty corresponding to the mean value of a single observation is calculated as follows:

Mean error of the arithmetical mean

$$= \frac{\text{mean error of a single observation}}{\sqrt{N}}$$

The measure of uncertainty of the mean corresponding to the probable error of a single observation is calculated as follows:

Probable error of the arithmetical mean

$$= \frac{\text{probable error of a single observation}}{\sqrt{N}}$$

Values for all of the foregoing measures of precision have been calculated for each sample and are presented in Table 7. Values for the average deviation of a single observation, or "mean deviation," and for the mean error of the arithmetical mean are given both in parts per million and parts per thousand F^-. Values for the other quantities are given only in parts per million F^-.

Values for all mean deviations were calculated on the basis of the "rounded" rather than the exact mean values for the individual samples. Since such a procedure may sometimes result in appreciable errors, the values of the possible corrections for each sample were calculated as follows:

$$\text{True mean deviation} = M.D. + \frac{(\bar{X}' - \bar{X})(F_a - F_b)}{N}$$

where $M.D.$ = mean deviation on basis of "rounded" mean; $\bar{X}'$ = actual value of the mean; $\bar{X}$ = rounded value about which $M.D.$ is calculated; F_a = sum of deviations above $\bar{X}'$; F_b = sum of deviations below $\bar{X}'$; and N = number of values for given sample.

There is only one sample, No. 16, for which a significant correction is obtained. In this case the uncorrected mean deviation is 0.50 p.p.m. F^- and the corrected mean deviation is 0.48 p.p.m. F^-.

Inspection of the data presented in Table 7 shows that the two methods of expressing the accidental error attaching to a single observation, i.e., the mean deviation and the probable error of a single observation, yield almost identical values for a given sample. The same is true of two of the methods for expressing the uncertainty of the mean, where the average deviation of the arithmetical mean and the probable error of the arithmetical mean are practically the same. Furthermore, if the samples are listed in order of decreasing precision, the relative order is very nearly the same, no matter which measure of precision is employed. On any basis, it appears that the best precision was attained in the case of Samples 2, 10, 17, 15 and 1 and the poorest in case of Samples 4 and 8. The poor precision in the latter two samples is to be expected in view of their low fluorine content and the fact that, with very few exceptions, values were reported only to the nearest 0.1 p.p.m. F^-. This does not mean that the results in case of these samples are unsatisfactory, for it is believed that, poor as they are in point of precision, they are still amply accurate for most practical purposes. Inspection of the analytical data for Sample 4, for example, makes this clear. Rejecting the two high values, it will be noted that the distribution and uniformity of the remaining 34 values is quite good. If each of the nine laboratories analyzing this sample had been requested to report only one rounded value, it seems evident from their results that eight of the nine would have reported either 0.7 or 0.8 p.p.m. F^-.

Omitting Samples 4 and 8, the average mean deviation or accidental error attaching to a single observation is 42 parts per thousand (p.p.th.), or 4.2 per cent, for the other 20 samples; and the average uncertainty of the mean for these samples is 7.8 p.p.th. or 0.8 per cent. Two additional factors, however, must be taken into consideration in evaluating the absolute precision obtained. The first is the fact that the number of determinations per sample is much larger than would ordinarily be made and the precision on any basis has therefore been increased. It is important to remember, however, that the precision increases only as the square root of the number of determinations. If, for example, the average deviation of the arithmetical mean of four determinations is X, then to double the precision by reducing the average deviation to 0.5 X will require 16

determinations. Since a total of 618 acceptable values have been used for 22 samples the average number of values per sample is 28. Therefore, the precision has been increased only on the average about 2.7 times what it would presumably have been with only four equally trustworthy values.

The second factor has to do with the fact that a number of laboratories participated in the work and that several different methods were used. In such cases, the usual procedure is to calculate the probable error of each analyst's mean value for a given sample, and then to multiply this probable error by some reasonable arbitrary

TABLE 8

Probability, Expressed in Numerical Odds, That, for Indicated Multiples of the Probable Error of the Arithmetical Mean on Either Side of the Arithmetical Mean, the Best Representative Value Will Fall Within the Limits so Established

NO. OF PROBABLE ERRORS	PROBABILITY FACTOR	NUMERICAL ODDS	
		Without Range	Within Range
0.1	0.9462	18	1
0.2	0.8926	8	1
0.5	0.7359	11	4
1.0	0.5000	1	1
1.5	0.3117	5	11
2.0	0.1773	3	14
2.5	0.0918	1	10
3.0	0.0430	1	22
3.5	0.0182	1	54
4.0	0.00698	1	142
4.5	0.00240	1	416
5.0	0.00074	1	1,350

factor, usually 3 or 5, the product representing the uncertainty of the result. Results of different workers are then regarded as consistent if they show at least one common value within limits so established.

It is possible to calculate by statistical methods the probability that, for any given multiple of either the average deviation of the arithmetical mean or the probable error of the arithmetical mean, the best representative value will fall within limits so established. Some of these are shown in Tables 8, 9 and 10.

For example, referring to Table 8, it is seen that if limits of three times the probable error of a single observation are established above

or below the arithmetical mean, the odds are 22–1 that the best representative value will fall within the limits so established. If the multiple two is used, the odds are only 14–3 that the best value will fall within those limits. If the multiple is four, the odds are 142–1, and if the multiple is five, the odds are 1,350–1.

TABLE 9

Probability, Expressed in Numerical Odds, That, for Indicated Multiples of the Average Deviation of the Arithmetical Mean on Either Side of the Arithmetical Mean, the Best Representative Value Will Fall Within the Limits so Established

NO. OF AVERAGE DEVIATIONS*	PROBABILITY FACTOR	NUMERICAL ODDS	
		Without Range	Within Range
0.1	0.93641	15	1
0.2	0.87321	7	1
0.5	0.68994	9	4
1.0	0.42494	3	4
1.5	0.23137	3	10
2.0	0.11054	1	8
2.5	0.04607	1	21
3.0	0.01668	1	59
3.5	0.00523	1	190
4.0	0.001415	1	706
4.5	0.000330	1	3,000
5.0	0.000072	1	14,000

* Average deviation of the arithmetical mean.

TABLE 10

Probability That the Best Representative Value Will Fail to Lie Within Limits Set by Indicated Number of Multiples of the Average Deviation of the Arithmetical Mean on Either Side of the Arithmetical Mean

PROBABILITY	NO. OF AVERAGE DEVIATIONS
0.001	4.1240
0.002	3.8730
0.01	3.2283
0.02	2.9156
0.10	2.0616
0.20	1.6062
0.50	0.8454
0.90	0.1575
0.98	0.0315
0.99	0.0157

Since the overall probable error of the arithmetical mean has been calculated to be 7.8 p.p.th., or approximately 0.8 per cent, the use of a multiple of three means that the odds are 22–1 that the best representative value will fall within ±2.4 per cent of the respective arithmetical means. These limits in parts per million of fluorine may be obtained by multiplying the values in the extreme right hand column of Table 7 by three.

TABLE 11

Variations of Individual Values From Means

SAMPLE NO.	VALUES RETAINED	MEAN VALUE IN P.P.M.	NUMBER AND PERCENTAGE OF VALUES DISTRIBUTED AS FOLLOWS:													
			Mean Value		Mean ±0.1		Mean ±0.2		Mean ±0.3		Mean ±0.5		Mean ±0.7		Mean ±1.0	
			No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	38	6.5	13	34	20	53	25	66	30	79	35	92	36	95	38	100
2	35	8.0	18	51	20	57	22	63	28	80	34	97	35	100	—	—
3	33	1.7	7	21	26	79	29	88	33	100	—	—	—	—	—	—
4	34	0.75	24	71	—	—	34	100	—	—	—	—	—	—	—	—
5	30	6.3	4	13	12	40	18	60	22	73	27	90	30	100	—	—
6	28	3.7	4	14	12	43	18	64	25	89	27	97	28	100	—	—
7	25	2.7	9	36	20	80	24	96	25	100	—	—	—	—	—	—
8*	17	0.13														
9	32	3.5	3	9	14	44	23	72	27	84	29	91	32	100	—	—
10	30	4.4	11	37	24	80	28	93	30	100	—	—	—	—	—	—
11	20	6.8	1	5	6	30	9	45	10	50	17	85	18	90	19	95
12	9	3.7	3	33	6	67	7	78	8	89	9	100	—	—	—	—
13	43	7.1	2	5	13	30	20	47	24	56	33	77	35	81	39	91
14	31	1.7	8	26	27	87	30	97	31	100	—	—	—	—	—	—
15	26	3.7	5	19	24	92	26	100	—	—	—	—	—	—	—	—
16	24	14.4	1	4	3	12	3	12	6	25	17	71	22	92	22	92
17	30	14.0	17	57	18	60	19	63	22	73	23	77	24	80	28	93
18	30	2.9	8	27	19	63	22	73	23	77	28	93	30	100	—	—
19	32	5.9	2	6	10	31	15	47	22	69	29	91	30	94	32	100
20	32	2.3	7	22	21	66	31	97	32	100	—	—	—	—	—	—
21	36	8.2	6	17	11	31	22	61	23	64	30	83	34	95	36	100
22	35	2.7	13	37	28	80	33	94	35	100	—	—	—	—	—	—

* Results cannot be indicated as above; see analysis.

It has been shown above, however, that the average precision has been increased some 2.7 times over what it presumably would have been had only four equally trustworthy values been available. Then it would appear reasonable to assume that, if the values for the probable errors of the arithmetical means given in the last column of

Table 7 are multiplied by 2.7 and these values in turn multiplied by a selected factor, limits would thereby be established which would apply to the individual worker who has made four determinations. Using the factor of 3, the total multiplying factor becomes 8.1 and it appears finally that the odds are 22–1 that the best representative values will fall within ± 6.3 per cent of the arithmetical means of the respective samples. The numerical odds for other multiples may readily be obtained by reference to Tables 8, 9 and 10.

If it can be assumed that all of the values used are equally trustworthy and that the distribution of the accidental errors has followed the "Law of Chance," it seems reasonable to conclude that the overall precision of the results is good and that the fluorine content of the samples has been determined within very close limits. This being true, it becomes possible to proceed with some assurance with the evaluation of the effects of certain variables and also with a comparison of the results obtained by some of the methods employed.

Table 11 presents an analysis of the data in a form which is possibly of greatest interest to the average worker. The number of values retained for each sample and the rounded mean of these values are shown, followed by the number and percentage of values falling exactly on the mean and varying from the mean within limits set forth at the top of the vertical columns. It will be of interest to use the data in Tables 7 and 11 as the basis for certain comparisons.

Effect of Mineral Content of Samples on Precision

A study of the data quickly makes evident the difficulty of drawing conclusions regarding the effect of the mineral content of the samples on the precision obtained. For example, Samples 2, 3, 5, 10, 12, 13 and 14 may be classed as relatively high in sulfates, all containing in excess of 300 p.p.m. $SO_4^=$ ion. They are also high in dissolved solids, varying in this respect from 798 to 4,730 p.p.m. Yet the highest precision of the entire investigation was attained in Sample 2, containing 439 p.p.m. $SO_4^=$ ion and 1,619 p.p.m. dissolved solids. The average deviation of a single observation is only 18 p.p.th., or less than 2 per cent and the uncertainty of the mean only 3 p.p.th., or 0.3 per cent. Of its 35 values 18 fall exactly on the mean and 34, or 97 per cent, are within 6 per cent of the mean.

Sample 10 contains 514 p.p.m. $SO_4^=$ ion and about 2,000 p.p.m. dissolved solids, yet the precision of its results is third highest of all samples.

Sample 14, next highest of all samples in sulfate content with 838 p.p.m. $SO_4^=$ and containing 1,806 p.p.m. dissolved solids, yields values of remarkable precision when its relatively low fluorine content of 1.7 p.p.m. is considered. Of a total of 32 values, only one was rejected. Of these remaining values, 27, or 87 per cent, are within 0.1 p.p.m. of the mean, 30 values, or 97 per cent, are within 0.2 p.p.m. and the one remaining value differs by 0.3 p.p.m. F^-.

Sample 13, with 1,130 p.p.m. $SO_4^=$ ion is highest of all samples in sulfates and its content of 2,541 p.p.m. dissolved solids places it second only to Sample 12 in this respect, yet the precision of its results is only slightly less than the mean of the 20 best samples. While only two of its 43 values fall exactly on the mean, 35, or 81 per cent, fall within 10 per cent of the mean; and of the 43 values, the highest number obtained in any sample, none had to be rejected.

Sample 13 may be compared at this point with Samples 19 and 21, slightly lower and higher respectively in fluorine content. Both of the latter samples are relatively low in dissolved solids, less than 300 p.p.m. Sample 21 contains 95 p.p.m. $SO_4^=$ ion and Sample 19 only 6.6 p.p.m. Yet the precision of the results for Sample 13 is almost exactly the same as that of Sample 19 and is not greatly inferior to that obtained for Sample 21.

An interesting comparison with respect to the possible effect of total dissolved solids may be made in the case of Samples 20 and 22, of approximately equal fluorine content. Sample 20 contains 1,365 p.p.m. dissolved solids and 61 p.p.m. $SO_4^=$ ion whereas Sample 22 contains less than 50 p.p.m. dissolved solids and only 5 p.p.m. $SO_4^=$ ion. The precision in Sample 22 is somewhat better than the average, whereas that for Sample 20 is slightly less than the average, but the mean deviations would be identical if reported to the nearest 0.1 p.p.m., both being 0.1 p.p.m. F^-.

Samples 16 and 17 afford another interesting comparison. These samples, practically identical in fluorine content and highest of all samples examined, are quite different in chemical character in other respects. Sample 16 contains about 500 p.p.m. dissolved solids, largely sodium carbonate and bicarbonate but is unusually high in silica. It contains no sulfates. Sample 17 contains 953 p.p.m. dissolved solids, largely sodium bicarbonate and sodium chloride. It contains 37 p.p.m. $SO_4^=$ ion. Yet both the precision and the distribution of values about the mean are far better in the case of Sample 17 than for Sample 16. Seventeen, or 57 per cent, of the 30

values for Sample 17 fall exactly on the mean, whereas only one of the 24 values for Sample 16 falls on the mean and the overall distribution is much poorer.

The high silica content of Sample 16 has been mentioned and it is of interest to check all the other samples for this constituent. Three others are unusually high, Samples 1, 6 and 9. In these, the precision of Sample 1 is unusually good, it being one of the five best samples, but the precision of Samples 6 and 9 is below the average.

It will be noted that Sample 16 contains a trace of phosphate, as do Samples 6 and 9, but that no phosphate is shown in the analysis of Sample 1. A study of the chemical analyses of all waters discloses two things. First, one other, Sample 10, is shown to contain 0.2 p.p.m. phosphate ion, highest of any of the four in which the ion appears, yet the precision of Sample 10 is third best of all 22 samples. Second, and most significant, is the fact that Samples 6, 9, 10 and 16 were analyzed by the same laboratory, the only one reporting any determinations of this ion. It is probable therefore that other samples contain undetermined traces of phosphate.

The negative or contradictory results of this type of reasoning are a good illustration of the difficulty, or even the impossibility, of drawing valid conclusions when several different variables are involved.

Most interesting of all, perhaps, is the fact that the averages of the mean deviations and the uncertainty of the means for the seven "high sulfate" samples are almost identical with the corresponding averages for the 20 best samples. The average mean deviation of the twenty best samples is 42 p.p.th., or 4.2 per cent, whereas, for these seven samples it is 41 p.p.th., or 4.1 per cent. The average uncertainty of the mean for the 20 best samples is 7.8 p.p.th., or 0.8 per cent, and the average value for the seven samples is 7.9 p.p.th., or 0.8 per cent. It would appear, therefore, that neither sulfates nor total dissolved solids need be limiting factors in the determination of the fluoride ion in water by the methods to be recommended, if the procedures are followed carefully.

Samples 3, 4, 7, 14, 20 and 22 contain the fluoride ion in quantities varying from 0.75 to 2.7 p.p.m., the range within which small variations assume relatively great importance from the standpoint of dental health and within which the determination needs to be made with the greatest possible exactness. Using the data of Table 7, it is found that the average mean deviation of these six samples is 57 p.p.th.,

or 5.7 per cent, as compared to 42 p.p.th., or 4.2 per cent for the 20 best samples. Sample 4, however, was one of the two omitted from that average because of its low fluorine content. Omitting it from the above list, it is found that the average mean deviation of the remaining five samples is 47 p.p.th., or 4.7 per cent, only slightly above the average. The average uncertainty of the arithmetical mean for the above six samples is 18 p.p.th., or 1.8 per cent, and,

TABLE 12

Effect of Fluorine Content of Samples on Precision

SAMPLE NO.	MEAN VALUE IN P.P.M.	NUMBER AND PERCENTAGE OF ALL VALUES DEVIATING FROM MEAN AS INDICATED		DEVIATION	
		No.	%	p.p.m.	%
4	0.75	24	71	±0.05	6.7
3	1.7	29	88	±0.2	11.8
14	1.7	27	87	±0.1	6.0
20	2.3	31	97	±0.2	8.7
22	2.7	33	94	±0.2	7.4
7	2.7	24	96	±0.2	7.4
18	2.9	28	93	±0.5	17.2
9	3.5	29	91	±0.5	14.3
12	3.7	8	89	±0.3	8.1
15	3.7	24	92	±0.1	2.7
6	3.7	25	89	±0.3	8.1
10	4.4	28	93	±0.2	4.5
19	5.9	29	91	±0.5	8.5
5	6.3	27	90	±0.5	8.0
1	6.5	35	92	±0.5	7.7
11	6.8	18	90	±0.7	10.3
13	7.1	39	91	±1.0	14.1
2	8.0	32	91	±0.4	5.0
21	8.2	34	95	±0.7	8.5
17	14.0	28	93	±1.0	7.1
16	14.4	22	92	±0.7	4.9

omitting Sample 4, drops it to 8.3 p.p.th., or 0.8 per cent, the same as the average of the 20 best samples. Even if Sample 4 is not omitted from the above averages, the precision is good and quite satisfactory for ordinary requirements.

This may be demonstrated in another way. Inspection of Table 8 shows that the percentage of the values for each sample falling within ±0.2 p.p.m. of the respective means of the samples is 88 per cent for

Sample 3, 100 per cent for Sample 4, 96 per cent for Sample 7, 97 per cent for Sample 14, 97 per cent for Sample 20 and 94 per cent for Sample 22; yet an inspection of the chemical analyses of these samples reveals the fact that they vary widely in both the amount and the character of the dissolved mineral constituents.

In Table 12 the precision is calculated on a different but closely comparable basis and expressed in parts per hundred, or per cent. On this basis it will be noted that only five samples have a precision of less than 10 parts per hundred, or 10 per cent. Of these five samples, No. 13 and No. 3 are high in sulfates, containing 1,130 and 380 p.p.m. $SO_4^=$ ion respectively; Sample 9 is of medium sulfate content, containing 197 p.p.m. $SO_4^=$ ion; and Samples 18 and 11 are quite low in sulfate content, containing 44 and 0.8 p.p.m. $SO_4^=$ ion respectively.

Relationship of Fluorine Content of Samples to Precision

A study of the data presented in Tables 7 and 11 makes it apparent that, in general, the precision obtained throughout the work is of the same order of magnitude and very largely independent of the fluorine content of the samples, the two outstanding exceptions to this rule being Samples 4 and 8. In these samples, the very low fluorine content and the fact that results were reported only to the nearest 0.1 p.p.m. F^- have inevitably resulted in poor precision when calculated on any basis. It is for this reason that these two samples have not been included in the averages which are used in the report.

Table 12 presents this uniformity of precision in a different way. The first and second columns list the samples in regular order of increasing fluorine content, Sample 8 being omitted. The third column gives the number and percentage of acceptable values falling within indicated limits with respect to the mean, the limits being chosen so that the percentage of all values for each sample will be as near 90 per cent as possible, thus making them closely comparable. The fourth column gives the percentage deviation of the respective deviations which are expressed as parts per million in the third column. It will be noted that, on this basis, the best precision has been obtained in Sample 15, containing 3.7 p.p.m. fluorine; second best in Sample 10, containing 4.4 p.p.m. fluorine and third best in Sample 16, containing 14.4 p.p.m. flourine. Of the samples whose precision on this basis is less than 10 per cent, one, Sample 3, contains 1.7 p.p.m. fluorine; two, Samples 18 and 19, contain 2.9

and 3.5 p.p.m., respectively, and two, Samples 11 and 13, contain 5.8 and 7.1 p.p.m., respectively. Averaging Columns 3 and 4 reveals the fact that 574, or 91 per cent, of the acceptable values for 21 samples fall within 8.4 per cent of the mean values of the respective samples. If Samples 3, 18, 9, 11 and 13 are omitted, 431, or 91 per cent, of the acceptable values for the remaining 16 samples fall within 6.8 per cent of the mean values of these samples.

TABLE 13

Number of Values Obtained by Individual Methods

METHOD	VALUES OBTAINED	VALUES REJECTED
Sanchis A	111	4
Sanchis B	131	1
Sanchis D	88	1
Elvove (Original)	47	1
Elvove (Modified)	40	0
Elvove (Uncorrected)	13	3
Distillation and Sanchis A	12	0
Distillation and Sanchis B	35	1
Distillation and Sanchis D	19	1
Distillation and Titration	47	1
Foster	21	0
Other	74	7
Total	638	20

Comparison of Results Obtained by Individual Methods

Table 6 presents for each individual sample the number of values obtained by each method used and the mean of each of these sets of values; and all values obtained by all methods used are presented in Table 5. These data may be assembled and analyzed in a number of different ways in order to make pertinent comparisons.

Table 13 gives the total number of values obtained by most of the methods employed. A total of 74 values were obtained by a variety of special methods and are collectively grouped in the table under the designation "Other." If information with respect to values obtained by any of these methods is desired, this may be obtained by referring to the individual samples and the explanatory notes there given.

It will be noted that a total of 330, or 52 per cent, of the 638 values were obtained by means of the original Sanchis method or by one or the other of the two modifications employed. It is immediately evident that since the mean value for each individual sample has been obtained by averaging all acceptable values, it has been weighed more by values obtained by these methods than by those of any other method. The question of the fairness of comparing the results of individual methods using a mean value so obtained as a criterion immediately presents itself and must be given consideration. It is answered in part by a study of the data of Table 6, for such study immediately makes apparent the rather remarkable uniformity which exists with respect to the means of values obtained by the individual methods. It is further answered by a consideration of Tables 14 and 15.

TABLE 14

Comparison of Individual Methods on the Basis of Deviations From Mean Values by All Methods

METHOD	NUMBER OF SAMPLES WHERE MEAN VALUE BY METHOD INDICATED CHECKS MEAN VALUE BY ALL METHODS			
	Exactly	± 0.1 p.p.m.	± 0.2 p.p.m.	> ± 0.2 p.p.m.
Sanchis A	7	9	4	1
Sanchis B	10	8	2	1
Sanchis D	7	9	4	1
Elvove (Original)	7	8	2	4
Elvove (Modified)	4	12	1	4
Distillation and Sanchis B	3	7	2	8
Distillation and Titration	7	3	8	2

In the first column of Table 14 are given the number of samples where the mean value obtained by each method checks the mean of all values for that sample. In the other three columns are given the number of samples where the mean value obtained by the individual method differs from the mean of all values for the sample by deviations as indicated. Here again uniformity is evident, somewhat more so in the case of the first five methods than the last two. Sample 8, which contains only a trace of fluorine, is omitted from all these comparisons and Sample 12 is not included in the case of the last two methods of the table, no values by these methods having been reported for this sample. This tabulation shows that the number of

cases where the mean by an individual method checks the mean of all methods or differs from it by only 0.1 p.p.m. is practically the same for each of the first five methods, although Scott's modification, designated as "Sanchis B," is somewhat better on this basis than the other four and the modified Elvove method has the poorest distribution of the five methods. The distribution of values for the last two methods is definitely not as good as in the case of the first five and the argument advanced above can be brought forward here without refutation.

In Table 15, these same seven methods are compared as to the distribution of values above and below the mean. The first column gives the number of samples considered; the second, the number of cases, for each method, where the mean by the individual method

TABLE 15

Distribution of Mean Values by Individual Methods With Respect to Mean Values by All Methods

METHOD	TOTAL NO. OF VALUES	NO. CHECKING MEAN EXACTLY	NO. HIGHER THAN MEAN	NO. LOWER THAN MEAN
Sanchis A	21	7	11	3
Sanchis B	21	10	4	7
Sanchis D	21	7	8	6
Elvove (Original)	21	7	8	6
Elvove (Modified)	21	4	8	9
Distillation and Sanchis B	20	3	3	14
Distillation and Titration	20	7	1	12

checks the mean by all methods exactly. The third column gives the number of cases where the mean by the individual method is higher than the mean by all methods and the fourth, the number of cases where it is lower.

It will be noted that the Sanchis B, or Scott modification method, gives the largest number of values falling on the means, and that the modified Elvove method and the method employing distillation and titration give the least number falling on the means. The four other methods are exactly equal on this basis. With respect to values falling above and below the means, the Sanchis A method exhibits a definite tendency to yield values above the means whereas both methods employing distillation exhibit an even greater tendency to yield values below the means. The Sanchis B method exhibits a slight

TABLE 16

Comparison of Values Obtained by Sanchis and Elvove Methods
(Numbers in parenthesis give number of determinations)

SAMPLE NO.	MEAN OF ALL VALUES RETAINED	PARTS PER MILLION F^- BY METHOD INDICATED				
		Direct Sanchis			Elvove	
		A	B	D	Orig.	Modif.
1	6.5	(7) 6.5	(7) 6.5	(5) 6.3	(2) 6.6	(2) 6.5
2	8.0	(6) 8.2	(7) 8.0	(5) 8.0	(2) 8.1	(2) 7.9
3	1.7	(6) 1.7	(8) 1.8	(5) 1.8	(3) 1.8	(2) 1.8
4	0.75	(6) 0.70	(8) 0.72	(5) 0.78	(1) 0.80	(2) 0.85
5	6.3	(5) 6.5	(6) 6.3	(4) 6.5	(3) 6.0	(2) 6.0
6	3.7	(5) 3.7	(4) 3.7	(3) 3.6	(2) 4.1	(2) 3.8
7	2.7	(4) 2.7	(5) 2.7	(3) 2.8	(2) 2.7	(1) 2.7
8	0.13	0.10	0.06	0.10	—	—
9	3.5	(6) 3.6	(6) 3.6	(5) 3.4	(2) 3.3	(2) 3.3
10	4.4	(6) 4.5	(6) 4.4	(5) 4.4	(3) 4.5	(2) 4.5
11	6.8	(3) 7.0	(4) 6.5	(3) 7.1	(1) 6.9	(1) 6.8
12	3.7	(2) 3.8	(2) 3.8	(1) 3.6	(1) 3.7	(1) 3.4
13	7.1	(8) 7.4	(7) 7.0	(6) 7.2	(3) 6.8	(3) 6.7
14	1.7	(6) 1.7	(8) 1.6	(4) 1.7	(1) 1.6	(2) 1.6
15	3.7	(5) 3.7	(6) 3.7	(4) 3.6	(2) 3.6	(1) 3.6

TABLE 16—*Concluded*

SAMPLE NO.	MEAN OF ALL VALUES RETAINED	PARTS PER MILLION F^- BY METHOD INDICATED				
		Direct Sanchis			Elvove	
		A	B	D	Orig.	Modif.
16	14.4	(4) 14.0	(6) 14.4	(3) 14.2	(1) 15.0	(1) 15.0
17	14.0	(4) 14.0	(6) 14.0	(4) 14.2	(3) 14.0	(2) 14.1
18	2.9	(5) 3.1	(5) 3.0	(2) 3.0	(3) 2.9	(2) 3.0
19	5.9	(5) 6.0	(6) 5.7	(4) 5.9	(3) 5.7	(3) 5.8
20	2.3	(5) 2.2	(6) 2.1	(4) 2.3	(3) 2.3	(3) 2.3
21	8.2	(6) 8.2	(7) 8.1	(5) 8.2	(3) 8.2	(2) 8.3
22	2.7	(6) 2.8	(7) 2.7	(5) 2.7	(3) 2.7	(2) 2.6

tendency toward low values but this is more than compensated for by the high ratio of values on the mean. The other three exhibit almost perfect distribution of high and low values.

The thought occurs that the definite tendency toward low results exhibited by the methods employing distillation may be due to consistent failure to effect complete recovery during distillation. A great deal of careful preliminary work carried out by several committee members, however, has indicated quite definitely that essentially quantitative recoveries may be effected by proper technic.

When the committee was formed it was specifically instructed, not only "to perfect present laboratory methods of determining the fluoride content of water," but also "to make a comparative study of the Sanchis and Elvove methods." Such a comparison has already been presented in broad outline in Tables 14 and 15. For the convenience of those who wish to carry this comparison further, the results obtained by these methods on all waters studied are presented in Table 16. Both the original Sanchis method and the two modifica-

tions studied are included, as are both the original and the modified Elvove methods. As in Table 6, the small numbers in parenthesis are the number of determinations by the method in question, the rounded mean of the values obtained appearing just below them.

Of the total of 105 mean values by the indicated individual methods, Sample 8 being excluded, only *two* differ by as much as 10 per cent from the mean of all values for that sample. They are the value of 0.85 p.p.m. obtained by the modified Elvove method on Sample 4 and the value of 4.1 p.p.m. obtained by the original Elvove method on Sample 6. Of the 105 mean values, only twelve, including the two above, differ by as much as 5 per cent from the respective mean values by all methods. In other words, 93, or 88.5 per cent, of the 105 means by individual methods differ by less than 5 per cent from the respective means by all methods. Employing a different and cumulative method of comparison, 39 individual means, or 37 per cent, check the "overall" means exactly, 79 values, or 75 per cent, check them to ± 0.1 p.p.m. and 93, or 88.5 per cent, check them to $\pm$ 0.2 p.p.m. It is probable that, without a single exception, every mean value by each of the five technics here compared is sufficiently close to the "overall" mean values to meet most practical requirements.

If reference is made to Table 5, it will be noted that only four of the ten co-operating laboratories used the Elvove method in its original or modified form, whereas nine used the original Sanchis method or one of its modifications. This fact must be kept in mind in interpreting the data and making comparisons. The same thing can be said, however, for the methods involving distillation, since only three of the ten laboratories used such methods. This seems to indicate quite clearly either the inability of the chemist, faced with the necessity of making large numbers of fluoride determinations, to devote the necessary time to these more elaborate technics, or the definite desire for a simple and rapid method—or possibly both.

In the light of the results obtained, it would appear that if the procedures presented as part of this report are carefully followed, the Elvove and Sanchis methods yield results of approximately equal accuracy and precision, with consequent saving of time and labor very much in favor of the Sanchis technics. It would appear further that Scott's modification of the original Sanchis method, designated in this report as "Sanchis B," offers a still greater saving of time and labor without sacrificing either accuracy or precision.

Special Comments on Scott Modification

When using Scott's modification, the effect of temperature of the samples upon their apparent fluoride content must be taken into account. Scott himself was the first to note very pronounced effect. His comments on this point are as follows:

"The color of the lake is affected by temperature. Thus, the color of 0.5 p.p.m. F^- plus reagent after one hour at 32°C. is about that of 1.0 p.p.m. F^- at 14°C.

"This does not influence the accuracy of the determination, providing samples and standards have the same temperature, but if they differ, then the temperature of the samples should be brought to that of the distilled water used in preparing the standards before adding the reagent."

During the course of the work some committee members experienced difficulty in securing a clear solution in mixing the alizarin sodium sulfonate solution and the zirconium nitrate solution (see Section II. 1.3 under "Procedures for Methods Used," p. 1973). Scott's comment on the order of mixing reagents is as follows:

"If the alizarin sodium sulfonate solution is slowly added to the zirconium nitrate solution, a clear solution is obtained. If the order of mixing is reversed, the solution is turbid, but clears within 30 minutes, after which no difference is noted in the appearance of the solutions or in their sensitivity. Accordingly, the order of mixing does not seem of much significance."

Summary

1. An intensive study has been made of the most important factors affecting the precision and accuracy of each of the following methods of determining fluorides in water:
   a. Sanchis method.
   b. Elvove method in its original form and in its modified form.
   c. Method of distillation and titration.
   d. Distillation and colorimetric determination of fluoride in the distillate.
2. Two modifications of the Sanchis technic have been developed by members of the committee, as follows:
   a. The modification developed by Scott, and designated in this report as "Sanchis B."
   b. The modification suggested by Collins and designated in this report as "Sanchis D."

3. Detailed procedures for all methods or modifications of methods enumerated in Items 1 and 2 above have been presented.

4. Detailed procedures for certain other methods used by some members of the Committee have been presented.

5. Through the co-operation of the boards or departments of health of sixteen states, a total of 22 different samples of water varying in fluorine content from 0.10 to 14.0 p.p.m. have been furnished to all or most of the ten co-operating laboratories, and have been analyzed by some or all of seventeen different methods or modifications thereof. The data are presented as part of this report.

6. On the basis of all work done, the following statements may be made and the following conclusions drawn:

a. Of a total of 638 values reported for the 22 samples studied, only 20, or 3.1 per cent, have been rejected on the basis of mathematical treatment.

b. The "overall" mean deviation or uncertainty of a single observation, based on 20 samples, has been found to be 42 p.p.th., or 4.2 per cent of the mean values of the individual samples.

c. The "overall" average deviation of the arithmetical mean, based on 20 samples, is 7.8 p.p.th., or 0.8 per cent of the mean values of the individual samples, and the probable error of the arithmetical mean is slightly but not significantly less than this value.

d. It has been found that, in the case of the waters examined, total dissolved solids up to 4,730 p.p.m. and $SO_4^=$ ion up to 1,130 p.p.m. do not interfere to a significant extent in the determination of the fluoride ion in water by the methods used. This does not mean, however, that these concentrations represent the permissible upper limits for these constituents.

e. The precision obtained throughout the investigation has been found to be of the same general order of magnitude and appears to be independent of the concentrations of total dissolved solids, of the fluoride ion, or of any other ion present in the samples used. This statement does not apply in its entirety in the case of two samples containing very low concentrations of the fluoride ion.

f. Striking uniformity and close agreement have been found between the mean values obtained by individual methods and the rounded mean of all values reported for a given sample

by all methods used for the particular sample. This has been found to be true in the case of all samples examined.

g. The Elvove method in both its original and modified forms and the Sanchis method have been found to yield results of essentially equal accuracy and precision in case of the 22 waters examined, with a consequent saving of time and labor very much in favor of the latter method.

h. The Scott modification of the Sanchis method has been found to make possible a still greater saving of time and labor without sacrificing either accuracy or precision.

i. Methods involving distillation have been found to have a tendency to yield a value for a given sample slightly lower than the mean of values obtained by all methods used for that sample. This has been found to be true in 26 cases out of 40. In practically all cases, however, the differences are small.

j. It has been established definitely that standing for extended periods of time, in containers of either soft glass or resistance glass, has no appreciable effect on the fluoride content of water samples. This statement holds for periods up to one year, as far as this investigation is concerned.

Acknowledgements

The wide range in the fluorine content and chemical character of the 22 waters used by the Committee was made possible by the splendid co-operation of the Boards or Departments of Health of sixteen states. The names and titles of the co-operating officials are given in the report and to them and to other executives and officials of these states with whom correspondence has been conducted, the hearty appreciation of the Committee is tendered. To the list should be added the name of G. F. Catlett, former Sanitary Engineer of the Florida State Board of Health, whose co-operation in many ways is gratefully acknowledged.

In order to make apparent the full extent of the co-operation thus extended, the following figures are presented. These State Boards of Health collected, bottled and shipped at their own expense a total of 174 one-gallon samples of water to the ten co-operating laboratories. The average shipping distance was 920 miles per sample. This means that somewhat more than 0.7 ton of water was shipped by express for an average of 920 miles or about 644 ton-miles. To these

shipping costs must be added the cost of collecting and bottling the samples in the field, all borne, as previously stated, by these co-operating Boards of Health.

Appreciation is also expressed to Elias Elvove, J. M. Sanchis and Margaret D. Foster for advice and suggestions with respect to methods developed by them and used by the Committee.

The laboratory work at the University of Florida was carried out under the direction of the Chairman by three chemists employed on a Fluoride Research Project and financed by the Work Projects Administration of Florida. Acknowledgment is also expressed to the Work Projects Administration for some clerical help during the progress of the work and in the preparation of the final report.

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Modification of the Fluoride Determination

By R. D. Scott

THE determination of the fluoride content of water supplies is now an essential procedure in many areas where it is desired to ascertain whether sufficient fluoride is present to cause dental fluorosis and where the efficiency of fluoride removal treatments are to be checked. Most of the determination methods employed are based on the decolorization of a zirconium-alizarin (or other anthraquinone derivative) lake in proportion to the fluoride present.

Now in general use, the Sanchis procedure (1), based on Thompson and Taylor's adaptation (2) of DeBoer's method (3) is briefly:

> Volumes of 2 ml. each of 3 *N* hydrochloric acid, 3 *N* sulfuric acid and indicator (zirconium nitrate-alizarin sodium sulfonate) are added to 100 ml. of water sample (previously filtered if turbid) and to fluoride standards in 250-ml. flasks. These are heated just to boiling and allowed to cool for 4 hr. or overnight. The contents are then transferred to Nessler tubes and color comparisons made. The standard solution of fluoride contains 0.2211 gram sodium fluoride, NaF, in 1,000 ml. distilled water. 1 ml. contains 0.1 mg. fluoride, F.

The procedure may be applied either to the original sample or to a distillate (4). Various recorded data indicate that distillation is unnecessary for waters of ordinary composition.

This technic is time-consuming and has certain other disadvantages in that the colors which develop are not as clear and bright as desirable, the color gradation of the standards is not always regularly progressive, and, occasionally, a precipitation of the zirconium-alizarin lake occurs.

After employing the Sanchis technic for some time, the author modified it by adding the two acids as a single solution instead of separately, and adding acid, zirconium salt and dye as a single reagent.

A contribution by R. D. Scott, Chief Chemist, Laboratory Division, Department of Health, Columbus, Ohio.

This modification not only has the obvious advantages incident to using one reagent instead of three, but also it is found that decolorization of the lake proceeds rapidly at room temperature, so that color readings may be made without undue delay. It was also observed that the color change is complete in about 50 min. so that samples can be compared with the standards one hour after adding the reagent. The final colors are consistently clear and sharply defined and no precipitation of the lake occurs.

Either the nitrate or oxychloride of zirconium may be used in this determination, but, as found by Nichols (5), the reagent prepared with the oxychloride is much more stable.

1. Reagents

1.1. Dissolve 0.43 gram zirconium oxychloride in 50 ml. distilled water. The solution should be perfectly clear. (A satisfactory zirconium oxychloride was obtained from A. D. Mackay, 198 Broadway, New York, N. Y.)

1.2. Dissolve 0.1 gram alizarin sodium monosulfonate (alizarin red S) in 50 ml. distilled water and pour slowly with stirring into the zirconium oxychloride solution.

1.3. Prepare an approximately 3 *N* hydrochloric acid solution by diluting 135 ml. concentrated acid, Sg. 1.19, to 500 ml. and an approximately 3 *N* sulfuric acid solution by diluting 43 ml. of concentrated acid, Sg. 1.84, to 500 ml. After cooling, mix the two acid solutions. Place 70 ml. of the zirconium-alizarin solution in a 1-liter flask and make up to the mark with the mixed acid solution.

The reagent is red as first prepared, rapidly changes to an orange-yellow color (within an hour) and is then ready for use. The red color of the lake returns on dilution; on adding 5 ml. to 100 ml. of water containing no fluoride, the initial yellow color soon changes to pink. The reagent should be stored in the dark when not in use.

2. Procedure

To 100 ml. of water sample and a series of standards up to 2.0 p.p.m. F contained in 100-ml. Nessler jars, add 5 ml. of the reagent, accurately measured from a volumetric pipette. Mix and compare sample with standards after standing one hour at room temperature. If the fluoride content is more than 1.4 p.p.m. repeat with a suitable aliquot made up to 100 ml. with distilled water. The sensitivity over the range 0 to 1.4 p.p.m. F is uniform; as little as 0.05 p.p.m. F produces a definite color change.

Since the color of the zirconium-alizarin lake varies with temperature, sample and standards should have the same temperature, within one or two degrees before adding the reagent.

(On completion of a set of determinations it is well to rinse out the Nessler jars with concentrated hydrochloric acid followed by distilled water, to remove any film of dye which may have adhered.)

3. Interfering Substances

3.1. In any method for fluoride which involves the decolorization of a lake the concentration of iron, aluminum, sulfate and chloride should received consideration. The limiting concentrations for iron and aluminum are about 0.5 and 0.2 p.p.m., respectively. A 1-p.p.m. quantity of iron causes an apparent increase in the recorded fluoride of about 0.05 p.p.m., while 1 p.p.m. aluminum causes an apparent decrease of about 0.1 p.p.m. F. If the water sample is filtered through a retentive paper, however, the aluminum content of the filtrate rarely exceeds 0.05 p.p.m.; and if the water is aerated and allowed to stand for several hours the iron content of the filtrate is unlikely to exceed 0.1 p.p.m.

3.2. Sulfate interference is greatly suppressed by the high sulfuric acid content of the added reagent, so that up to 250 p.p.m. SO_4 no correction is needed. Each additional 100 p.p.m. causes an apparent fluoride increase of about 0.05 p.p.m.

3.3. With chloride up to 500 p.p.m., interference is suppressed by the hydrochloric acid present in the reagent. Each additional 1,000 p.p.m. chloride causes an apparent fluoride decrease of about 0.1 p.p.m.

(It should be noted that these limiting concentrations are as present in the determination, and if an aliquot of the sample is taken the concentration of possible interfering substances is lessened, in practically all cases, to a point where no interference is caused.)

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Specifications for Filtering Materials

Committee Progress Report

As a progress report of the Committee on Specifications for Filtering Material, this paper does not present any conclusions, but is intended to review briefly the present status of information and thought regarding filtering material used in connection with rapid sand filters. The Committee is instructed specifically to consider and recommend standard specifications for filtering materials. Before specifications can be presented, however, the following items must be taken into consideration:

1. The physics of the behavior of water passing through filtering material as used in connection with rapid sand filters.
2. The conditions under which filtering material is used in relation to other elements of the process of purifying water by rapid sand filtration, such as coagulation, sterilization, softening and special treatments.
3. The technique of testing filtering material by sieving and otherwise.
4. The latitude which should be allowed in the selection of the filtering material.

Much has been written on the theoretical hydraulics of filtering material. This is a complicated subject on which further research and study are, undoubtedly, advisable. On the other hand, much has been learned regarding the practical hydraulics of filter sand and other filtering materials as a result of numerous tests that have been conducted by various workers, with particular reference to rapid sand filtration in conjunction with coagulation and sedimentation. The principal factors upon which present day attention is centered with reference to the behavior of filtering material in rapid sand filters comprises the following:

A committee report presented on June 25, 1941, at the Toronto Convention by Paul Hansen, *Chairman*, Chicago, Ill.

1. Other things being equal, the length of filter runs between washings vary with the size of the sand grains, roughly in proportion to the 2.15 power of the effective size (according to Baylis).

2. Other things being equal, the length of filter runs varies with porosity. This is a factor not fully appreciated until recently.

3. There is a limit of size and a limit of porosity in relation to size, which should not be exceeded for good filtration. What this size is and what the limit of porosity is are still uncertain. With good coagulation, the size of the sand may be large, e.g. 1 mm., and the porosity great, e.g. 55 per cent. With weak coagulation, however, turbidity may pass through filters with effective sizes even as low as 0.40 mm. and porosities as low as 40 per cent.

4. The shape of the sand grain affects size as determined by a sieve analysis, as, for example, angular and elongated sand grains, on sieve analysis, give sizes smaller than the actual sizes. Elongated and angular grains also increase porosity.

5. Sand in rapid sand filters is partially stratified as a result of backwashing, but not so much so as formerly supposed. Moreover, it has been observed that while the major portion of the straining process takes place in the upper layers, the lower layers, even to a depth of 24 in. or more, are sometimes importantly effective. It is also to be noted that deep layers have a greater depth of fine material at the top than shallow ones, and this has an effect on filtration.

6. It has become apparent to a number of observers that in rapid sand filter practice, there is no one effective grain size that is controlling, but rather a range of grain sizes that influence the process.

Conditions of Filter Use

Conditions of use of sand for rapid sand filters vary considerably. The question of whether a standard specification will be applicable to all conditions may well be raised. For example, certain waters are always easier to coagulate than others. Some raw waters are relatively free from serious pollution so that adequate bacterial removal is more readily obtained. Some filters are used in conjunction with softening plants in which the use of hydrated lime may have an important purifying effect. Some are used under circumstances where provisions are made for effective coagulation even during periods that ordinarily result in weak coagulation. Some sands are used in connection with relatively old installations that have inade-

quate provision for preliminary treatment, whereas others are used in plants equipped with the latest and most adequate provisions for pre-treatment.

Testing of Filter Sands

The technique of analyzing or testing filter sands needs considerable attention. As pointed out above, filter sands of elongated or angular grains are apt to show smaller sizes than actually exist. This suggests the importance of examining the shapes of sand grains in connection with the analysis. By a similar line of reasoning, it would seem important to have an accepted standard sand with nearly spherical grains of exceptionally uniform quality for calibrating sieves.

Inasmuch as there is considerable difference of opinion on the significance of the terms "effective size" and "uniformity coefficient," as hitherto defined, it seems desirable to pay more attention than is customary to the shape of the curve obtained by plotting sieve analyses on suitable plotting paper. In this connection logarithmic scales for sand sizes and probability scales for percentage separations by weight seem to have an advantage in giving smooth straight curves for the significant part of the analysis. For specification purposes, it is not necessary to show the curves. A tabulation may be given of limits between which grain sizes shall fall for the entire range of sizes allowed.

Several new expressions have been developed for describing or indicating the performance of filter sand, such as "effective size range in per cent by weight" and "average mean diameter within the effective size range." The old expressions, "effective size" and "uniformity coefficient," are also used. A review of these expressions and their meaning as applied to filtration should be examined, with a view to recommending their use or disuse and their relationship to each other.

The feasibility of obtaining testing sieves of a uniformity and accuracy that will render calibration unnecessary should be reviewed. At the time of the report of the last A.W.W.A. Committee on Filter Sand in 1926, no such uniformity and accuracy had been attained and the tolerances permitted by the United States Bureau of Standards were regarded as too liberal.

Some inquiry should be made into the latitude allowable in the selection of sands. Water works men who are conversant with the

present knowledge of filtering material and experienced in dealing with various types of water may exercise judgment in the selection of a filter sand. For example, circumstances may be such that a relatively coarse sand may be permissible with economy and good results, whereas in other instances a relatively fine sand may be necessary to obtain adequate results even though there may be a reduction in the economy of maintaining the filters in clean condition. There is also some latitude of choice with a view to utilizing a relatively inferior but inexpensive local sand, as compared with a high grade siliceous sand, furnished in the exact sizes desired, by a producer at a distant point. It is also recognized now that materials other than sand, such as anthracite coal, provide acceptable and sometimes preferable filtering material. These should be studied.

It is the purpose of the Committee during the ensuing year to discuss all of the foregoing items and to confer with various workers who have made a special study of the behavior of filtering material. An effort will also be made to induce experienced workers to make studies of factors, affecting filtration, for which there is not at present a sufficient body of reliable data, as, for example, the effect of porosity on filtration. Before the next convention, the committee will endeavor to offer a proposed standard specification for filtering material.

The Appendix to this report consists of abstracts of various papers and articles on filtering material, by H. E. Hudson, Jr., a member of the Committee. These abstracts should be very helpful to those wishing to pursue the study of filter sands.

The Committee invites correspondence with all workers who are interested in improved specifications for filter sand, to the end that the Committee may be placed in touch with them and enlist their assistance in its work.

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Appendix—Abstracts on Filtering Material

Prepared by H. E. Hudson, Jr.

Hazen (1) defined "effective size" as that size particle which is coarser than 10 per cent of the sample by weight, and "uniformity coefficient" as the ratio of the size coarser than 60 per cent to the 10 per cent size. He set forth his method of calibrating sieves by counting and weighing the grains which pass through the screen after prolonged shaking, computing their diameters as spheres from their weights and specific gravity.

Hazen proposed the method of determining sand size which has become standard practice. In plotting sieve analyses, he used as axes the particle size and percentage by weight. The latter are expressed as percentages by weight passing through the various screens, and these figures are usually totaled cumulatively to show the total proportion of sample which passes through each sieve. In plotting the data from the sieve analysis, the percentage passing each screen is plotted as an ordinate against the largest size particle which passes the sieve as an abscissa. The curve through these points is the locus of percentages finer or coarser than given sizes. Accordingly, the size particle for which the curve passes through any given percentage, for instance, n per cent, is called the n per cent size. Hazen emphasized the importance of considering the entire curve as plotted in judging the suitability of a sand for any given use.

In 1898, F. H. King (2) published a method of determining the effective size of a porous material by measuring the time of flow of a given amount of air through a sample at a given pressure. Although it was said to give more consistent results than the effective size determined by sieve analysis, this method never gained wide acceptance among water works men because it demanded a bothersome actual measurement of permeability on a sample. In 1899, King proceeded further and published an experimental confirmation (3) of a formula, derived through geometry and hydrodynamics by his colleague C. S. Slichter (4), embodying his effective size and the effect of porosity.

In 1902 and 1905, Slichter published further data upon this subject. Due to the difficulty of the method of determining the effective size, however, his formula has not been applied extensively, although it is probably more accurate than Hazen's. Slichter arrived at cer-

tain conclusions on the effect of porosity but presented no data to uphold his conclusions.

In 1903, Hazen republished his method for mechanical analysis of sands in his book, *The Filtration of Public Water Supplies* (5). Therein he also discussed the testing of sand with acid to detect soluble material.

In 1905, W. R. Baldwin-Wiseman gave the results of some experiments on samples of rock. He found the flow to increase faster than the pressure. It is believed that this resulted from clogging of the pores with turbidity. This article was followed by several others and, in 1909 (6), he presented his formula for the flow through porous materials, which, instead of effective size, used the surface area per unit volume of filtering material. It is believed that his formula was empirical. Because of the difficulty in making the surface area computation, it has had little use.

Hazen's formula was used quite widely, but with indifferent success in some cases. In 1911 (7), he reiterated some of the limitations on its use, stating among other things that sieve analysis for determining effective size should be made as he had set forth (1), and that the formula was not applicable to sands of more than 3.0 mm. effective size. In sands larger than this, the pores are no longer capillary, and hence, above certain velocities, turbulent flow exists.

Lack of Uniformity in Sieves

In 1915, Burgess (8) reviewed the status of filter sand analysis. He expressed dissatisfaction with the effective size measurement, pointing out that materials used in rapid sand filters are much more uniform than those used in slow sand filters. Burgess argued that the term, "effective size" is confusing to contractors and that there is a difference between the actual sizes of sand and the sieve openings in the screens. Since few engineers are equipped to calibrate screens and since the Bureau of Standards has established standard specifications for testing sieves, he recommended that the sieve opening, instead of the particle size, be used.

In his article Burgess gave data on sieve calibrations which showed considerable differences in results. He recommended that filter sands be specified by stating the range of sizes rather than the effective size and the uniformity coefficient. In discussing this paper, Hazen

pointed out that screens are still so lacking in uniformity as to make calibration by counting and weighing necessary. Even if uniform sieves were available, calibration and the expression of particle size on the basis of calibration would, he felt, be desirable.

As a result of the Burgess paper the A.W.W.A. formed a committee to study filter sand testing and recording. This committee reported in 1918 (9). Owing to the use of wires of different diameters by the sieve manufacturers, which resulted in different size openings for the sieves designated to have a certain number of meshes per inch, the committee recommended that the sieves be designated by the width of the opening in millimeters, instead of in meshes per inch. This method of designating sieves, however, never came into general use.

The committee also recommended that plain woven wire cloth instead of twilled cloth be used. Twilled cloth was then used for some of the sieves of small size openings. A method for making the mechanical analysis of the sand was also given. This method was substantially that given by Hazen, but was more explicit in some details. A 300-gram sample of the material was recommended for sieves 8 in. in diameter and it was specified that a mechanical shaker be used. A table showing the relation between sizes of opening and sizes of separation of the sieves was given. The ratio of the size of separation to opening was approximately 1:1, though it varied somewhat from this figure. The ratio was slightly higher for the small size openings and less for the larger size openings.

This committee report probably resulted in more attention to the manufacture of sieves. A few years later another A.W.W.A. committee on filter sand analysis was appointed, making its first report in 1924 (10), and another in 1925 (11).

Validity of Hazen's Sand Index

In 1924, the Committee on Filtering Materials of the A.W.W.A. raised the question of whether or not to discard Hazen's 10 per cent size (1). The Committee wished to stimulate discussion and research. It was suggested that Abram's fineness modulus (used in proportioning concrete) or some other such modulus might be applicable.

Soon afterward, Charles Terzaghi (12) published his noted studies on soil mechanics, in which he included a formula for the flow through porous materials. This formula is very much like that of Slichter, differing only in the porosity effect. Its weakness, like that of

Slichter's formula, lies in the determination of the effective size *D*. Terzaghi suggests testing each in a "permeameter" to determine its permeability (resistance to flow) and then, knowing all other factors, its effective size.

The Committee on Sand Testing and Recording made another progress report in 1926. This report urged standardization of sieves by manufacturers, suggesting tolerances on sieve openings and wire diameters. The Committee felt strongly that there was need for redefinition of the terms, "effective size" and "uniformity coefficient," agreeing that the effective size term does not indicate the importance of the upper 6 in. of the filter layer in filtration.

In 1925, R. G. Tyler (13), published the results of some experimental work carried out along the line suggested by the Committee on Filtering Materials. Finding Hazen's effective size unreliable, he suggested the possibility of using a size index called the "surface median size." Owing to the fact that this index was obtained by somewhat involved computation, this suggestion was not widely used.

In 1926, Tyler, Danielson and LeBosquet (13) set out the results of their research. They corroborated Tyler's earlier suggestion of using a "surface median size" or surface modulus, and tested another size index called the "Specific Surface." Their work was too brief to be conclusive, but it does contain indications that it may be worth while to investigate the expression of the hydraulic properties of a porous material with some such modulus.

N. D. Stearns (14), in 1927, described some very painstaking experiments on the permeability of soils which proved that Darcy's law holds for small hydraulic gradients. Stearns tried to use the 10 per cent size in Hazen's formula without success, and found the method of determining effective size given by King unsatisfactory also. She stated that it is evident some new term to define the effective hydraulic size of porous materials must be found. This paper contains a great deal of valuable data on the permeability of soils, which are worthy of more thorough analysis.

An editorial (15) in 1930, pointed out the weakness of Hazen's size index and, in 1931, a symposium giving the views of eleven well informed water works men on the use of the 10 per cent size and the uniformity coefficient appeared. There was considerable disagreement about whether this size index should be discarded or retained. At about this time the researches of Hulbert and Feben at Detroit were begun, and G. M. Fair was working on the subject at Harvard.

In the symposium mentioned above, Fair stated his belief that the best indices of size and grading were the "geometrical mean size" and the "geometrical standard deviation." These are obtained from a plotting of the sieve analysis and are suggested because the sieve analyses of most filter materials show size distribution in accordance with probability equations.

Data on the hydraulic grading of filters during washing, and the penetration of floc during filtration were presented by J. W. Armstrong (16), who suggested that as the 10 per cent size is not an index of the action of the filter in operation, it should be dropped from use. He recommended "top size" as a better index of filter performance.

W. E. Stanley (17), later in the same year, published a clear outline of the situation, suggesting that the 10 per cent size be retained if possible because of its widespread use. He also outlined the directions in which research workers could turn to find the information of greatest value.

The Committee on Filtering Materials published the results of some experiments under its sponsorship in 1932 (18). In this report, the Baylis method for measuring sand size with a microscope was given. Baylis assumed that if sand grains be spread in a single layer with the grains separated on a counting cell, the shortest diameter would fall in a vertical direction. Measuring the shortest exposed diameter with a microscope may therefore give a good measurement of the average diameter of each particle.

Loss of Head Determinations

A very clear empirical study of the loss of head through rapid filter sands was published by Hulbert and Feben (19). From experiments on 25 different filter sands, they deduced a formula, with which the loss of head is computed for each sieve separation, the sum of these computed losses representing the total loss through the filter. The depth of each sieve separation is assumed to be proportional to the percentage of the sample (by weight) in each sieve separation.

In discussing the paper of Hulbert and Feben, Turner and Scott (20) said that they had been able to modify Hazen's formula to make it more accurate. They included the uniformity coefficient in the formula.

In the derivation of the Hulbert and Feben formula, porosity was considered. Later (21) they revised their method of determining porosity.

Black and Stutz (22), under the direction of H. E. Babbitt, tested a number of uniform sands in an effort to check the results of Hulbert and Feben. The former were unable to obtain consistent results with use of the Jackson tube porosity test as proposed by Hulbert and Feben. The Jackson tube test was found to give porosity values 4 to 10 per cent higher than the actual porosity in the backwashed filter.

Fair and Hatch (23) derived, theoretically, a formula showing the effect of various factors upon the flow of water through sand. This paper presents the most convincing derivation on the subject which has appeared; and the formula appears closer to the truth than any other. Yet it allows entrance of the personal equation in the estimation of the shape factor and then squares that factor, thus increasing possible error.

Harmeson and Hasfurther (24) tested about 10 unstratified sands and derived a formula intended for use in connection with ground waters. They worked out the definition: "the effective size is the average of the 4, 6, 32, 50 and 70 per cent sizes. Their work included some study on well drawdown.

In 1934, Baylis (25, 26) published comprehensive information on the effect of sand size on filter runs. His method of correlation of these two factors included a new method for determining the effective size of sand. Using this method he obtained very precise correlation of the results from 22 glass tube filters, each operated daily for more than a year, containing sands covering a wide variety of effective sizes and uniformity coefficients. Baylis showed that the filter runs vary as the 2.15 power of the effective size. Various other researchers have given some information on the effect of sand size on filter runs, but in no case is the data as extensive as that of Baylis. Hence, it may be assumed that, until further information is presented, the relation given by Baylis is nearest the truth.

Use of Coal in Filters

Farrell and Turner (27) described experiments on nine 4-inch tile filters. Apparently neither coagulant nor rate controllers were used, and conditions did not parallel practical plant operation. Turbidity measurements appear to have been accurate to about 1 p.p.m. The authors concluded that anthracite as a filtering material is superior to sand. Filter coal was later tried by Farrell (28) in pressure filters at Bethlehem, Pa. Rate of filtration was 4 g.p.m. per sq.ft. Filters

were run to at least 18 ft. loss of head; no coagulation was used. Effective sizes and porosities are not given. From the 22 tests given in the paper it is concluded that, "a new coal filter is as efficient as a hair-matted sand filter."

Turner and Scott (29) presented a brief discussion of some experiments on filtration of laboratory-coagulated waters through layers of anthracite and sand. Details and extent of experiments are not given. Results presented indicate that anthracite produces an effluent superior to sand.

In a plant trial of a layer of anthracite at Columbus, Ohio (30) a coal filter delivered an effluent equal to sand filters. In 1935, Ripple (31) described experiments at Denver in which the routine operation results of four large filters over a nine-month period were compared. These data indicate that coal produces an effluent equal in quality to sand while giving 60 per cent longer filter runs.

Ripple appears to have been the first to suggest the use of a layer of coarse coal on top of a bed of finer sand. He later published information (32) on the use of such a combination filter, indicating that it gave longer filter runs and clearer effluent than a sand filter. Baylis (33) has tested this same type of filter and states: "use of a layer of coarse material over one of finer material of higher specific gravity is a practical means of lengthening filter runs."

Relation of Floc Penetration to Filter Runs

Hulbert and Herring published information that a clean filter produces better water than one which has been allowed to "ripen." Their paper led the way to many experiments on the value of "Schmutzdecke" in producing clear water.

Numerous researchers since then have pointed out the fact that there is appreciable penetration of turbidity into the sand filter, and that, despite this penetration, clear water is still produced in many cases. Allan (34) published the results of extended experiments, in which he showed conclusively the penetration of coagulated matter into the filter layer and demonstrated that penetration increases with sand size. Filter runs were found to be almost directly proportional to floc penetration. The A.S.C.E. Committee on Filtering Materials also published results of experiments on floc penetration (35), from which a method of calculating the proper depth of filter layer from the sieve analyses and from acutal tests on floc penetration was deduced. The report concludes that sand having "top sizes" up to 1 mm. may

be used. Their idea was to provide a layer deep enough that no floc would penetrate entirely through it.

Camp, in discussing the A.S.C.E. committee report, presents excellent data collected by Eliassen (36) at the Providence Water Works on the actualities of filter clogging. Considerable information on floc penetration is given. It was conclusively shown that floc penetration is great, and that much of the straining action in a rapid sand filter takes place as far as 12 in. below the top of the bed.

Effect of Depth and Porosity on Filter Runs

On the basis of experiments, Baylis (37) recommends the use of the new effective size determination as applied to a layer 24 in. deep. He says layers of other depths will require slight adjustment in effective size to produce equal filtering quality. Baylis gave valuable data on the effect of depth of layer on filter runs and showed how this can be taken into consideration by correcting the effective size by a simple manipulation of the sieve analyses.

Baylis also included some preliminary information on the effect of filter porosity on filter runs. Tests on six materials were used in determining this relationship. A method for measuring the porosity of the filtering materials is given. In purchasing filter materials of the crushed type, he indicates that finer materials should be chosen when porosity is greater. The Chicago experiments described by Baylis indicated that filter runs may vary with a power of porosity in the neighborhood of 3. Variations from normal stratification should be considered in purchasing sand. The methods proposed by Baylis for measuring filter sand characteristics are probably the most important recent contribution to the knowledge in this field.

Smith mentioned experiments on glass tube filters at Richmond, Va. (38), from which he concluded that the glass tubes have very little value in determining plant operation. Smith felt that sands up to 0.65 mm. effective size might be used with well prepared waters, but that 0.45 mm. was a much better size when the filterability of the water varied.

Tiemersma-Wichers and Jacobs (39) explored the characteristics of filter sands and recommended that filter sands be chosen on the basis of the surface area per unit volume rather than on the basis of particle size and porosity.

A recent article by Riddick (40) recommends the abandonment of sand size measurement in millimeters, and suggests the sieve size instead.

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Ozonation at Whiting, Ind.

By James F. Bartuska

IN RESPONSE to public demand for better water, officials of the city of Whiting opened negotiations to purchase finished water from a neighboring city. At the same time a competent engineering firm was employed to make a thorough survey of the buildings, basins, pumps and equipment of the existing water filtration plant, to determine the feasibility of converting it into a sewage disposal plant. In the course of this survey one of the engineers, having become familiar with the raw water supply, commented: "It seems that you are already operating a sewage treatment plant." It was this situation which made it necessary for the city to take immediate remedial action, but such that would not increase water rates.

In the meantime a water treatment pilot plant, including a suitable ozone generating unit had been installed and operated for a long enough time to determine the practicability of improving Whiting water. The result of tests made with this pilot plant was the installation of the ozone process equipment now employed in the regular treatment of the city water supply.

The unusually heavy industrial and sanitary pollution of the raw water supply may be made more readily comprehensible by a description of geography of the region. The City of Whiting is located on the shores of Lake Michigan, about 3 mi. southeast of a point where the Illinois-Indiana state line meets the Lake. The marginal lake waters of this area are more or less enclosed by steel bulkhead breakwaters, running parallel to the shore and serving to form an artificial basin or bay, approximately 6 mi. long and 2 mi. wide at the center, but narrowing down to about 1 mi. at the northwest and southeast ends. The southeast end of this bay (the Whiting area) is enclosed

A paper presented on April 25, 1941, at the Indiana Section Meeting, Indianapolis, Ind., by James F. Bartuska, Superintendent, Whiting Water Department, Whiting, Ind.

on three sides by: (1) a breakwater 1 mi. in length and located about 1 mi. out in the lake, running parallel to the shore line; (2) "filled in" lands and piers of Indiana Harbor, east of Whiting; and (3) the shore line itself which runs in a northwest-southeast direction. The fourth or open side faces the center of the basin proper, which, in turn, is open to the lake by a 3-mile gap between the ends of the offshore breakwaters.

Much pollution enters the northwest end of the basin by way of the Calumet River system; sanitary sewers discharge directly into the lake along the shore line in the vicinity of Whiting; and most of the sewage of the highly industrialized Calumet region is dumped untreated into the area adjacent to Whiting's intake, which is located in the enclosed southeast end of the basin. In short, the untreated sewage from an estimated population of 250,000 and the industrial sewage of steel mills, oil refineries, chemical works, soap and corn products, and innumerable miscellaneous manufacturing establishments combine to create a water constantly fluctuating in characteristics and correspondingly hard to render safe and palatable.

A 1920–25 report issued by the U. S. Public Health Service said of the water in this area: "The pollution of Lake Michigan by sanitary sewage and industrial wastes, especially from Indiana, is such as to render the source of water supply now used by . . . Whiting . . . unfit for that purpose, even with elaborate and efficiently operated purification plants." Since the time of that report, of course, conditions have become progressively worse because of the great industrial expansion and population growth which have taken place in the interim.

Former Treatment Plant

In 1920 the pollution of Lake Michigan at Whiting was so bad that the city found it necessary to build a water purification plant at the south end of the lake. This first plant was designed for rapid sand filtration at a nominal capacity of 4 m.g.d. Treatment was carried out according to the following general plan:

1. Raw water aeration by 20 radial-vane "Spraco" nozzles.

2. Coagulant (aluminum sulfate) applied in mixing basin around-the-end baffles, with a mixing period of 6 min. at a rate of 3 m.g.d.

3. Pre-chlorination preceded by ammonia applied in a ratio of from 1:4 to 1:1, chlorine feed being adjusted according to chlorine demand tests made on raw water at 2-hour intervals.

4. Sedimentation in two basins operated in series, with a combined retention period of 6 hr. at 3 m.g.d.

5. Filtration in six rapid sand filters (nominal capacity each, 0.675 m.g.d.) at 1.5 g.p.m. per sq.ft. at 3 m.g.d.

6. Post-chlorination only as required.

7. Storage in a clear water basin of 900,000-gallon capacity.

The raw water treated in this plant was so grossly polluted that, at times, threshold odor numbers reached 300 and chlorine demand, for a 15-minute period, went as high as 48 lb. per mil.gal. The frequently applied high chlorine dosages that were required to maintain a residual for sterilization resulted in chlorine-trade waste combinations that produced very disagreeable tastes and odors. Laboratory and plant scale tests with activated carbon indicated that no effective dosage could be attained at reasonable costs. Extreme and suddenly changing chlorine demands introduced operating uncertainties that precluded the use of chlorine as a practical means of controlling tastes and odors.

Change to Ozonation

Finally, consideration was given to the use of ozone as a means of meeting these unusually difficult conditions. The history of ozone in water treatment was investigated. Its adoption by many European cities with apparent success over a period of years indicated that it would be worth a trial. Accordingly, a pilot plant was installed, and for about a year the practical and economic aspects of ozonation were investigated. The test results obtained indicated that the ozone process, adapted to meet Whiting's unusual requirements, would produce a water of satisfactory palatability and at a cost that was both reasonable and justifiable.

Plans and specifications covering the ozone process equipment, with a rated capacity of 50 lb. of ozone per day were drawn up, submitted to and accepted by consultants and also by the Indiana State Board of Health. Finally acceptance by the officials of the city of Whiting was received and equipment purchased, installed and put into service in July, 1940.

Ozone Equipment Installed

In the new treatment method, the only fundamental change made to the existing water plant was the substitution of ozonation for aeration as the first step in the treatment of incoming raw water

(Fig. 1). The raw water now enters directly into the top of two vertical open-top tanks (ozonizers) and flows downward to the outlets at the bottom, where ozonized air is applied through a grid of porous aloxite tubes. Thus the ozonized air-bubbles going up are retarded and held in contact longer by downward flowing water, which then enters the mixing basin, where coagulant is added, and continues onward through the normal processes of settlement and filtration.

The ozonizer tanks (Fig. 2), constructed of $\frac{3}{8}$-inch ingot iron and lined on the inside with hot-applied coal-tar enamel, are 8 ft. in diameter and 21 ft. in overall height. Around the outside and at the top of each tank is a circular grit channel, 2 ft. wide and 3 ft. deep, the top of the outer shell being 1 ft. higher than that of the top rim of the central or ozonizer tank proper. The water enters the grit channels

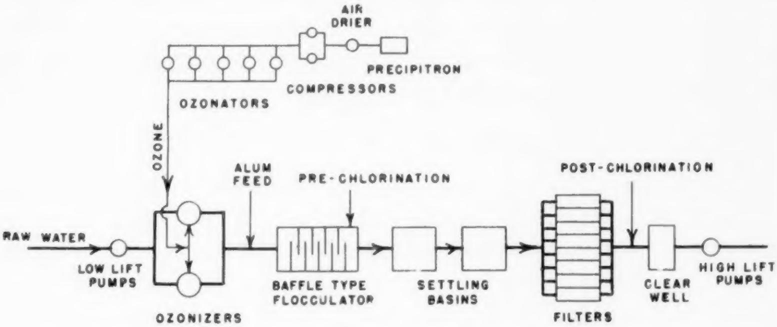

FIG. 1. Flow Diagram, Ozone Water Treatment Plant, Whiting, Ind.

through 12-inch tangential nozzles, which impart a circular centripetal motion, and flows over the top, into and down through the central tank. Each of the ozonizer tanks has a retention period of 11 min. at a rate of 1 m.g.d.

The ozonized air is introduced into the downward flowing water under pressure through the grid of porous aloxite tubes. These tubes, $2\frac{7}{8}$ in. in inside diameter, $4\frac{1}{2}$ in. in outside diameter and 30 in. long, have a permeability rating of approximately 4.0. There are eight in each tank, interconnected with a grid of piping. The tanks have conical bottoms and, since the diffusers are set at the base of the cone, the effective depth of water above them is approximately 16 ft. The amount of water being treated is controlled by manually operated valves in the effluent pipes of the ozonizers, and, since the ozonizers are considerably above the normal operating hydraulic

level of the plant, the water depth in the tanks is automatically held at 16 ft. by an air-operated throttling valve controlled by the head of water in the tanks.

As an aid to effective diffusion, motor-driven turbine type gas absorption agitators were installed immediately above the diffusers (Fig. 2). These agitators have curved-blade type wheels, 18 in. in diameter, set within a bladed stator ring and driven through 2-inch steel shafts by $1\frac{1}{2}$ h.p. vertically mounted motors at the tops of the tanks. In operation it has been found that these agitators increase

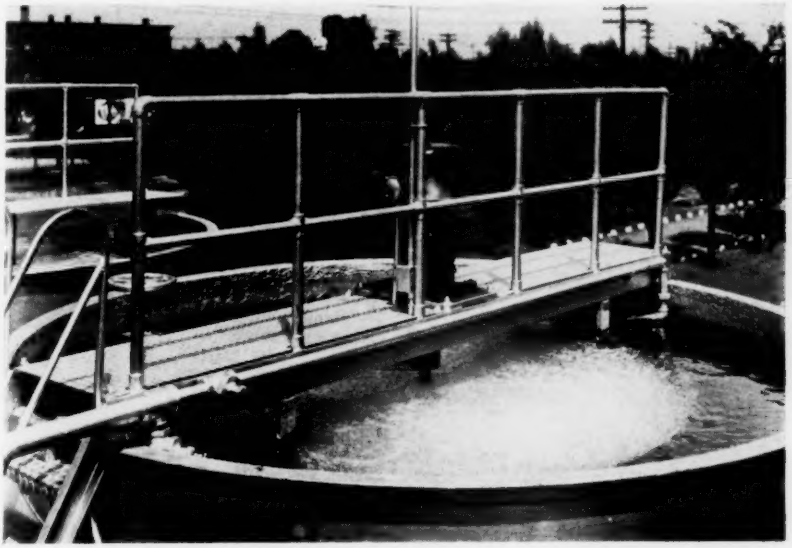

FIG. 2. 1.5-m.g.d. Ozonizer at Whiting; showing vertical motorized gear reduction unit driving submerged agitator for intensified mixing

absorption efficiency to some extent, but not sufficiently to compensate for their additional power consumption. Their use, therefore, has been limited to times of unusual pollution conditions.

The ozonized air is produced in a bank of 5 ozonators (Fig. 3), which, with auxiliary equipment, are located on the second or filter room floor of the water works. In appearance they are horizontal circular steel tanks with flat heads, mounted in a double tier. The sixth space is occupied by the control panel. The front head plates contain glass sight windows. External piping and wiring is at the rear of the bank.

For efficient ozone production, air must be carefully cleaned, dried, and compressed to approximately $1\frac{1}{2}$ atmospheres, or sufficient to overcome the hydraulic head of the ozonizers in addition to friction losses. The first step in this conditioning process involves cleaning the air in an electrostatic filter known as a "precipitron." In doing this, the dust particles are first ionized by passing the air between two tungsten wires energized with 12,000-volt direct current. It then passes through a collector cell composed of aluminum plates, energized at 5,000-volt opposite-potential direct current, on which the

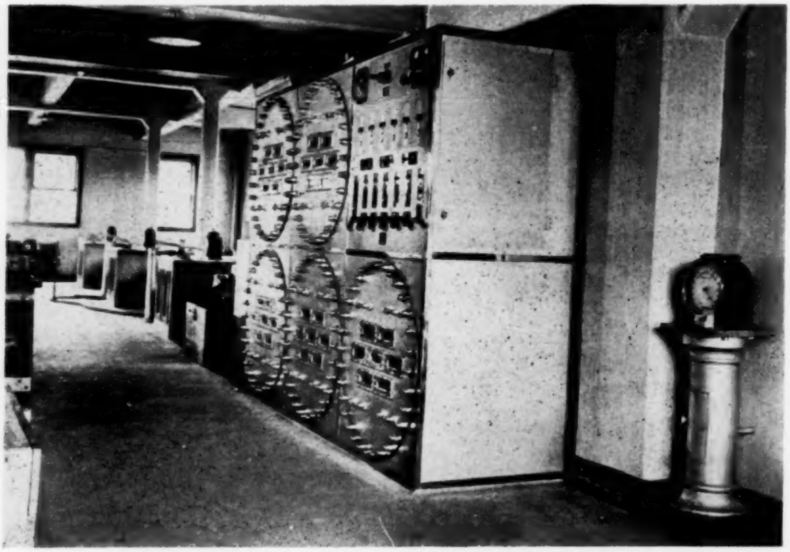

FIG. 3. Ozonators and Control Panel at Whiting; showing activated alumina air-drier control in foreground and filter controls in background

dust particles are collected by electrostatic attraction. Power is obtained from a power pack composed of a step-up transformer and vacuum type rectifier tubes.

After being cleaned, the air is dried to a dew point of less than -4°F. by means of a continuous-operation type activated alumina drier. The drier is a vertical cylindrical drum containing two 8-bed sets of activated alumina, one set above the other. Air is directed through individual pairs of beds in succession by means of a rotating valve so constructed that four pairs of beds are absorbing moisture at all times while three are being reactivated and one that has just

been reactivated is being cooled and purged in preparation for absorption.

Reactivation is accomplished by heat from a gas burner. The amount of gas used varies with and depends upon humidity conditions. After reactivation each bed is successively purged by passing cooled and dried air through it. This air is then wasted to the atmosphere before the bed is put back on absorption duty. After being passed through the drier, the heat of absorption is removed by means of a water-cooled after-cooler. Air is circulated through the drier by blowers driven by a single 1-h.p. motor, which also provides power for operating the rotating valve.

Although -4°F. (which represents a moisture content of 0.4 grains per cu.ft.) is considered to be the critical dew point for economical ozone production, dew points below -40°F. have been obtained with this machine without difficulty.

After passing through the air cleaner and dryer, which is on the suction side of the compressor, the air is compressed in two non-lubricated cylindrical reciprocating compressors having a piston displacement of 50 cu.ft. per min. at 10 lb. gage. These compressors are of the single-stage, double-acting, horizontal type, with water-cooled cylinders fitted with stainless steel-plate valves and split pistons. The main bearings, connecting rod bearings, and cross-head are oil-lubricated, but the pistons are fitted with carbon rings. Wiping glands are provided to prevent oil from entering the air cylinders along the piston rods.

The compressors are driven by two-speed motors and are each capable of compressing approximately 45 cu.ft. of free air per minute at about 8 lb. gage, making a total of 90 cu.ft. per min. for the two. At half speed the production is approximately halved. The pressure, of course, is increased slightly at higher velocities due to friction losses in the ozonators, piping, and diffusers.

The heat of compression is removed from the air by after-coolers, cooled with the water from the compressor cylinder jackets. A small air receiver on the line cushions the pulsations from the compressors. The air is then admitted directly to the shells of the ozonators in use.

Ozone is produced by a high-tension electric brush discharge, or corona, between two plate type aluminum electrodes insulated from each other by a $\frac{1}{8}$-inch glass plate and an air space of the same thickness in which the corona discharge occurs. Suitably filtered and dried air, under a pressure of about 8 lb. per sq.in. is passed through

the corona, which alters the molecular structure of a portion of the atmospheric oxygen through action not thoroughly understood. The ozonized air produced contains a concentration of from 0.5 to 1.0 per cent pure ozone, depending upon the velocity of the air stream and the voltage applied.

Plate voltages used range from 13,350 to 16,500 in steps of approximately 500 volts. High potentials are created from normal 220-volt current by individual $12\frac{1}{2}$-k.v.a. transformers mounted in each ozonator. Voltage variation is obtained by means of tap switches, mounted on the central control panel, which vary the number of primary turns in the ozonator transformer. There are 14 pairs of plate assemblies in each ozonator, making 28 corona spaces. Ozonized air is collected from the individual corona spaces in an aluminum header and conducted to the feed piping system through an aluminum pipe.

The electrodes are cooled by a forced draft provided by a propeller-type fan mounted inside the ozonator shell, and this draft also cools the transformer. The recirculated air is cooled in turn by tin-plated finned copper water coils inside the shell.

Distribution and Control Equipment

All pipes carrying ozonized air to ozonizer tanks are genuine black wrought iron with malleable-iron fittings lined with coal-tar enamel. Valves have iron bodies, straight chrome seats and dises with asbestos packing. The most exacting tests fail to reveal any decomposition of ozone in the piping system.

The ozonized air supplied to each ozonizer is measured through orifice type meters in the pipes, using water manometers to measure the differential. Pressure is measured with a mercury manometer.

All equipment is controlled from a panel (Fig. 3) built integrally with the bank of ozonators. The ozonator controls are interlocked with the individual fan switches and also with temperature and pressure controls, which automatically trip the circuit breakers in the event of failure of the fan motors, or of excessive temperature rise or inadequate pressure. The pressure switches also prevent power from being applied when an ozonator is open. In addition to switches, circuit breakers, and indicating lights for the various items of equipment, the panel carries a watt-hour meter to measure total power consumption, and a voltmeter and wattmeter to measure applied primary voltage and power consumption for each individual ozonator.

Control of Operation

The equipment is compactly installed and presents a very attractive appearance, requiring only about 175 sq.ft. of floor space per mil.gal. water treated. Though complicated of description, the plant is really very simple to operate.

The amount of ozone required for treatment naturally varies with the quality of the water, the dosage being by no means critical, provided it is sufficient to produce a measurable residual. Residual ozone reacts with ortho-tolidine in the same manner as chlorine, to produce the familiar pale yellow color, except that an indication of 0.15 p.p.m. on the chlorine comparator scale means only 0.1 p.p.m. of ozone. In general, treatment is adequate if a definitely measurable residual content is indicated by the ortho-tolidine test. Excess ozone is rapidly dissipated, disappearing entirely before the water treated has passed through the plant. The only reason for limiting dosage is to effect economy of operation, and such control presents no complicated problems, being merely a matter of pressing a few buttons and re-setting simple tap switches to vary the amount of ozone as required.

To avoid too abrupt a change in the finished water, ozone treatment was applied very gradually. Most of the intervening time was spent in developing a routine treatment procedure, instructing operators, testing and calibrating equipment and, in general, becoming familiar with all phases of operation. By October, 1940, operation had become a matter of routine and more time could be devoted to a study of treatment data and costs.

Comparative Data on Old and New Treatments

Since it is impossible for comparative purposes to operate the plant using the two systems simultaneously on the same raw water, comparison of treatment results or costs had to be made one period against another, where the raw water conditions were more or less equal in all respects. Therefore, to verify the similarity of raw waters used, Table 1 has been included here for the purpose of substantiating the comparableness of the data applying to the two different periods.

The raw water chlorine demands for March of both 1940 and 1941 are compared to show in more detail the similarity of raw water conditions typical of the time covered. The character of the pollution

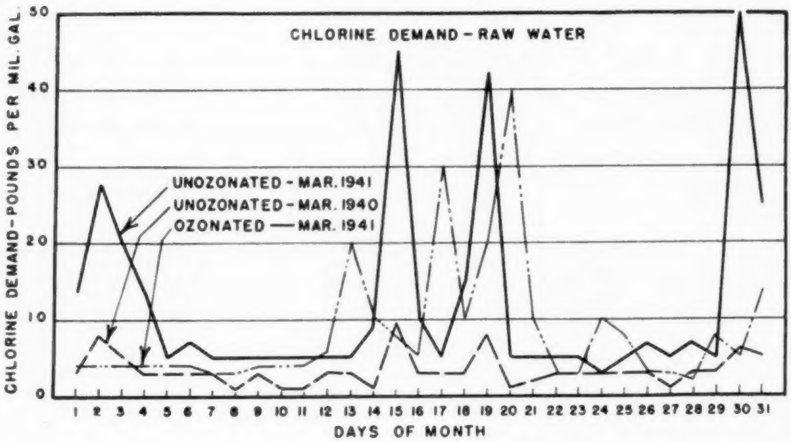

FIG. 4. Chlorine Demand—Ozonated and Unozonated (maximum for each day)

TABLE 1

Comparison of Raw Water Characteristics—1939–40 and 1940–41

MONTH	1939–40	1940–41
Average Turbidity		
	p.p.m.	*p.p.m.*
October	17.8	30.1
November	22.1	28.4
December	25.3	37.3
January	25.1	31.3
February	22.3	30.7
March	11.9	27.6
Average	20.8	30.9

Chlorine Demand

	1939–40 Average	1939–40 Maximum	1940–41 Average	1940–41 Maximum
	lb. per mil.gal.	*lb. per mil.gal.*	*lb. per mil.gal.*	*lb. per mil.gal.*
October	3.5	6	3.8	6
November	5.0	15	7.0	16
December	10.5	41	12.9	48
January	14.5	31	15.2	30
February	18.0	46	10.0	25
March	8.4	40	12.1	50
Average	10.0	46	10.1	50

has not changed, but the comparison using the chlorine demand as a measure of pollution, shows that the raw water of March, 1940, is, if anything, better than that of March, 1941, the latter being treated by the ozone process (see Fig. 4).

The five ozone generating units have a rated production capacity of 10 lb. per day each. Each unit, however, is capable of producing approximately 16 lb. per day, which excess capacity accounts for production in excess of rated capacity, as shown by operating results covering the six months from October, 1940, to March, 1941, inclusive (Table 2). Indicative of the fluctuating quality of the raw water is the amount of ozone used in treatment, as shown by the maximum, minimum and average dosage figures in the table. For

TABLE 2

Ozone Generated and Applied During Six Months, 1940–41

MONTH	AMOUNT USED PER DAY			TOTAL USED FOR MONTH	AMOUNT USED PER MILLION GALLONS		
	Max.	Min.	Ave.		Max.	Min.	Ave.
	lb.	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
October	40	12	19.5	606	18	5	9.5
November	81	13	31.1	933	43	7	15.7
December	72	11	28.2	875	37	6	13.7
January	51	12	27.0	837	23	6	13.1
February	70	10	17.7	496	35	5	8.5
March	64	9	19.8	614	32	5	9.8
Six-Month Period	81	9	23.9	4,361	43	5	11.7

November the maximum dosage was 43 lb. per mil.gal., the minimum, 7 lb. and the average 15.7 lb., while the average for the entire six-month period was only 11.7 lb. per mil.gal.

Threshold odor numbers on the raw, ozonized and finished waters were made using 250-ml. dilutions. Because of the fluctuating quality of the raw water, it was not always possible to get a sufficiently long "run" of the same kind of water to displace entirely the water already in the plant settling and filtered water basins, complete displacement of which would require about 16 hr. at normal rates. Therefore, more or less dilution would occur as waters mixed in passing through the plant, but, as far as possible, the element of time was considered in determining threshold odors, and such results were considered in evaluating treatment (Tables 3 and 4).

A comparison of ozone treated water (Table 3) with that of similarly polluted raw water that passed through the plant after receiving normal treatment prior to the adoption of ozonation (Table 4) shows that the old method resulted in an overall average reduction of only 58 per cent as compared with 83 per cent with the use of ozone. With

TABLE 3

Threshold Odor Numbers of Raw, Ozonized and Tap Waters, 1940–41

MONTH	NO. OF TESTS	RAW			OZONIZED			OZONIZED, COAGULATED, SETTLED AND FILTERED		
		Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
October	14	60	45	54	25	10	16	20	10	14
November	23	100	56	68	30	14	18	16	6	11
December	10	275	60	93	56	16	25	20	9	13
January	8	95	50	64	30	22	26	12	6	9
February	11	75	45	56	26	16	19	12	6	8
March	18	250	12	59	55	10	21	20	6	11
Six-Month Period	84	275	12	66	56	10	21	20	6	11
Percentage reduction from average raw water							68			83

TABLE 4

Threshold Odor Numbers of Raw and Tap Waters, 1939–40, Prior to Ozonation

MONTH	NO. OF TESTS	RAW			TAP		
		Max.	Min.	Ave.	Max.	Min.	Ave.
December	5	200	7	24	40	7	24
January	16	125	14	41	25	4	14
February	17	190	7	24	40	5	12
March	13	220	14	40	35	7	12
April	2	80	25	53	14	7	11
Five-Month Period	53	220	7	36	40	4	15
Percentage reduction from average raw water							58

the old system of treatment, any raw water that had a chlorine demand (15 min.) of 5 lb. per mil.gal. or more invariably entered the city mains with a threshold odor of 15 or higher, and had extremely disagreeable tastes and odors, decidedly noticeable and objectionable even in cold water.

Ozone treatment reduces the chlorine demand of the raw water

to such an extent that most of the time only enough chlorine and ammonia need be added to maintain a desirable residual (Fig. 4). Thus, by major reduction in the amount of chlorine, the formation of chlorine-tradewaste combinations is avoided. This is noticeable in the change in character of occasional tastes and odors in the finished water; the former disagreeable, musty, medicinal, oily and tar tastes being supplanted by an agreeable sweetish taste and odor that is acceptable in water with threshold numbers as high as 15.

The worst raw water, occurring periodically, with chlorine demands above 15 lb. per mil. gal., does result in a finished water having a noticeable taste and odor, but it is much more palatable than might be expected from the quality of raw water treated.

TABLE 5

Bacteriological Tests on Raw and Pre-Ozonized Water

DATE, 1941	COLIFORM INDEX—*M.P.N.*		TOTAL COUNT ON 37°C. AGAR	
	Raw	Ozonized	Raw	Ozonized
January 27	240+	8.8	—	—
January 28	—	—	900	40
January 29	—	—	600	30
January 30	—	—	750	35
January 31	—	—	900	42
February 3	240+	8.8	—	—
February 11	240+	8.8	800	45
February 11	240+	5.0	—	—
February 14	240+	5.0	950	50
February 18	240+	8.8	850	40
Average	240+	7.5	820	40

As a final trial treatment activated carbon was applied in dosages as high as 100 p.p.m. To determine the effect of activated carbon, water was siphoned from the outlet of the coagulant mixing basin (after ozonation of the raw water, but before carbon had been added), was diverted continously through a basin with a 6-hour retention period and then passed through a small rapid sand filter. The filter effluent was then compared with the water which had been treated with activated carbon and passed through the plant itself. In this test it was found that the reduction in taste and odor by activated carbon was not great enough to warrant the dosage applied, but further investigation is indicated.

An important property of ozone is its ability to function as a very effective sterilizing agent. Tests made on raw water before and after ozonation (no other treatment) in a series of tests (Table 5) showed an average reduction in coliform index from a most probable number of 240 to 7.5 and in total count on 37°C. agar from 820 to 40, an average reduction of over 95 per cent.

TABLE 6

Treatment Costs Prior to and After Ozonation—1939–40 and 1940–41

MONTH	WATER TREATED		ALUM USED		CHLORINE USED		AMMONIA USED		OZONE USED 1940–41
	1939–40	1940–41	1939–40	1940–41	1939–40	1940–41	1939–40	1940–41	
	mil.gal.	*mil.gal.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
October	61.538	63.964	11,467	9,443	568	302	122	119	606
November	54.461	59.292	10,326	7,480	439	414	113	149	933
December	53.936	63.668	10,515	9,005	501	437	232	160	875
January	71.760	63.715	11,559	9,833	703	389	377	80	837
February	57.988	58.487	10,025	8,775	594	382	321	94	496
March	58.767	62.215	10,421	9,942	492	371	200	91	614
Totals	358.450	371.341	64,313	54,478	3,297	2,295	1,365	693	4,361
Chemicals used, *lb. per mil.gal.*			179.4	146.8	9.2	6.18	3.8	1.87	11.74
Cost per pound, *cents*			1.21		7.5		17		25
Cost per million gallons treated, *dollars*			2.16	1.78	0.69	0.46	0.65	0.32	2.93
Savings,* %				18		33		51	

* This is based on cost of individual items; total costs are: 1939–40, $3.50; 1940–41, $5.49. The difference in total costs ($1.99) represents the *net* costs of ozone per million gallons treated.

Costs of Old and New Treatments

A determination of treatment costs must take into consideration the savings made possible by a reduction in the amount of treatment chemicals that would normally be consumed if ozone were not used to displace them partially. Since the similarity of raw waters treated during the two six-month periods being compared has already been established the amounts and costs of treatment materials may likewise be compared (Table 6, Fig. 5).

A watt-hour meter on the main feed line to the ozone equipment accounted for all power used by this equipment and its auxiliaries. Applying the power rates applicable to the power consumed, the following electric power costs are determined: average overall cost per kw.hr., 1.23 cents; average kw.hr. per pound of ozone, 16.28; and average total power cost per pound of ozone, 20.024 cents.

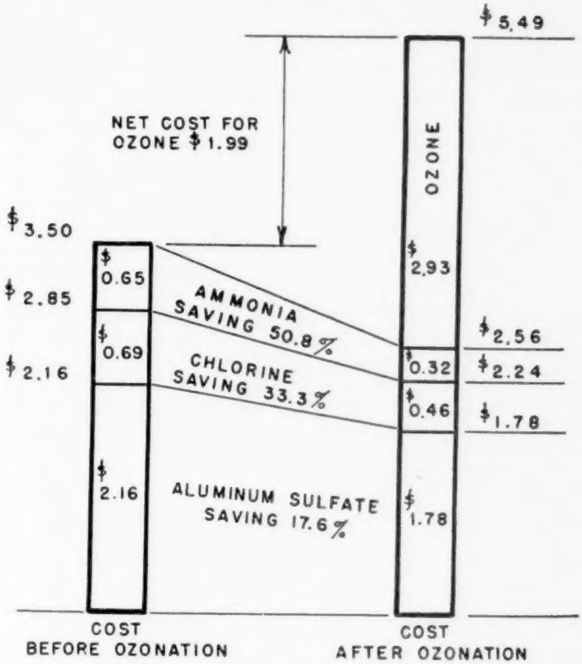

FIG. 5. Operating Costs per Million Gallons of Water Treated—Before and After Ozonation

A cubic foot gas meter registered all gas used for reactivating absorption beds in the dryer used to condition the air. Applying the gas rates applicable to the amount consumed, the following costs for gas were determined: average overall cost per 100 cu. ft. 11 cents; average number of cubic feet used per pound of ozone, 49.7; and average total gas cost per pound of ozone, 5.4 cents.

All of the foregoing may well be interpreted as a progress report on the development of ozonation practice at Whiting. Though it covers but six months of operation, that period of time coincides

with that of the worst raw water conditions and may be regarded as indicative of what to expect from ozonation as far as results and costs are concerned. As a matter of fact, the most recent operation indicates that minor changes in some of the auxiliary equipment, including: (1) installation of a duplex type gas burner in the air dryer, to enable appreciable reduction of gas consumption; (2) more frequent removal of accumulated dirt in the air cleaner; (3) periodic removal and cleaning of glass-plate electrode assemblies in the ozone generators; (4) smaller orifices in the chlorine and ammonia feed machines; and (5) reduction of residuals in the finished water, all point toward the probable reduction of operating costs in general.

Methods of Water Treatment and Laboratory Control

Committee Report

FOR the third successive year the committee has sent out questionnaires to all state and provincial sanitary engineers requesting information on outbreaks of intestinal disease. This year the questionnaire provided space for recording outbreaks from all causes. The returns are summarized on the accompanying tabulation, but they are by no means complete, particularly as regards outbreaks which were not water-borne. Where complete information was furnished it has been tabulated, but a number of states and provinces failed to supply complete information; hence the totals are not fully representative of the United States and Canada.

The number of outbreaks of intestinal diseases reported from all causes totalled 376, involving 47,772 cases, not including those classed as "sporadic." Of this total, 48 outbreaks were classified as definitely water-borne and 17 were attributed to public water supplies. Twenty outbreaks were listed as "possibly water-borne" and 12 of these were attributed to public water supplies. The majority of the outbreaks, namely 183, were classified as "gastro-enteritis" but only 26 of these were definitely water-borne and 9 were suspected of being water-borne. Seven of the former and 8 of the latter involved public water supplies. It is significant that out of the 35 outbreaks of gastro-enteritis where water supplies were involved the water was definitely shown to contain coliform organisms in 27 instances. The largest single outbreak of water-borne intestinal disease during 1940 occurred in Rochester, N. Y., as a result of the accidental contamination of the municipal water

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A Committee Report presented on June 25, 1941, at the Toronto Convention by George D. Norcom, *Chairman*, and Consulting Sanitary Engineer and Chemist, New York.

Relation of Public Water Supplies to the Occurrence of Intestinal Diseases From All Causes

NOTE: Data for 1940 were furnished by State and Provincial Sanitary Engineers, or by Epidemiologists where there are such. ***Where the complete data are shown, they are representative of the particular state or province but obviously the totals for the United States and Canada are incomplete.*** Where a report showed a zero, a zero is shown in the tabulation; where nothing was shown in the returned questionnaire, a dash appears in the tabulation; and where the report was given as a phrase or sentence, that is shown as a footnote relating directly to the state's name. Where cases were reported and no outbreaks cited, it has been assumed that all cases were sporadic.

KEY: GE—Gastro-enteritis; BD—Bacillary Dysentery; AD—Amoebic Dysentery; PT—Paratyphoid Fever; TY—Typhoid Fever; and Sp—Sporadic rather than epidemic.

STATES & PROVINCES	DEFINITELY WATER-BORNE			POSSIBLY WATER-BORNE			MILK-BORNE		FOOD-BORNE		DIRECT CONTACT		UNKNOWN VECTOR		TOTAL		FOOTNOTE		
	Outbreaks		Total cases	Outbreaks		Total cases													
	Total	P.W.S.[a]		Total	P.W.S.[a]		Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	b	c	d
Alabama	—	—	—	—	—	—	1BD	150	1GE	120	—	—	—	—	2	270	0	0	0
Arizona*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Arkansas	1TY	0	63	—	—	—	—	—	—	—	—	—	—	—	1	63	—	—	—
California	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Colorado	1TY	0	15	2TY[e]	0	14	—	—	—	—	—	—	SpBD	90	3	186	0	0	0
													SpAD	8					
													SpPT	9					
													SpTY	50					
Connecticut	1TY	0	4	0	0	0	—	—	—	—	—	—	—	—	1	4	0	0	0
Delaware	—	—	—	—	—	—	—	—	—	—	—	—	1TY[f]	10	1	10	—	—	—
Dist. of Columbia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Florida†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Georgia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Idaho	0	0	0	0	0	0	1TY	17	1GE	15	0	0	0	0	2	32	—	—	—
Illinois	0	0	0	0	0	0	0	0	5GE	209	0	0	0	0	6	218	0	0	0
									1TY	9									

Indiana	1TY	0	10	2GE[g]	2	235	1BD 1TY	50 4	3BD	43	2BD	14	0	0	10	356	0	2	0
Iowa‡	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Kansas	—	—	—	—	—	—	—	—	—	—	SpTY	6	SpBD SpAD SpTY	17 5 123	—	151	—	—	—
Kentucky	3GE[h] 1TY	2 0	3,904 20	1GE[i]	1	12	—	—	—	—	—	—	—	—	5	3,936	3	1	0
Louisiana§	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maine	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	0	0
Maryland	0	0	0	0	0	0	0	0	—	—	—	—	—	—	—	—	0	0	0

* 1940 data not available; 1939 data show 119 cases typhoid and 991 cases dysentery.

† No water-borne diseases or diseases suspected of being water-borne reported during 1940.

‡ No outbreaks of intestinal diseases reported in 1940 traceable through water or food.

§ Several cases typhoid classed as endemic; no outbreaks of diarrhea or dysentery recorded.

[a] Public Water Supply.

[b] Number of outbreaks of water-borne gastro-enteritis where the water supply was definitely shown to contain coliform organisms.

[c] Number of outbreaks of gastro-enteritis held to be water-borne because of epidemiological evidence but where coliform organisms were absent from samples examined in accordance with *Standard Methods*.

[d] Number of outbreaks of water-borne gastro-enteritis where known organisms of the Shigella (dysentery) group *were not* isolated but where known organisms of the Salmonella-Enteritidis group *were* isolated.

[e] One outbreak among small town residents drinking water from open stream—spasmodic outbreaks previously among these residents. Other outbreak among persons using raw water few miles below a city discharge of raw sewage.

[f] Fly-borne.

[g] Two small city populations served by filtered water from river completely frozen over during late January, 1940. After break up of ice, a great deal of foam appeared on river but usual laboratory procedures failed to reveal causes. Little or no chlorine residual was being maintained. Careful surveys after outbreaks clearly revealed public water supply as only common factor. Duration, severity, bloody stools and fever indicated an infection either bacterial or virus, rather than chemical irritant.

[h] Outbreak not a public water supply was supply furnished by industrial concern to company houses sheltering 108 persons, 104 of whom suffered from gastro-enteritis.

[i] Believed to be due to back-siphonage in apartment house.

Relation of Public Water Supplies to the Occurrence of Intestinal Diseases From All Causes

See beginning of tabulation for key and other notes

STATES & PROVINCES	DEFINITELY WATER-BORNE			POSSIBLY WATER-BORNE			MILK-BORNE		FOOD-BORNE		DIRECT CONTACT		UNKNOWN VECTOR		TOTAL		FOOTNOTE		
	Outbreaks		Total cases	Outbreaks		Total cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	b	c	d
	Total	P.W.S.[a]		Total	P.W.S.[a]														
Massachusetts	0	0	0	0	0	0	0	0	11GE	287	8BD	154	12GE	262	38	790	0	0	0
									1PT	29	1PT	3	2PT	34					
									1TY	13	2TY	8							
Michigan	0	0	0	3GE[j]	3	Many	0	0	0	0	0	0	—	0	3	Many	3	0	0
Minnesota	1TY	0	3	1GE[k]	0	10	0	0	1GE	212	1PT	3	36GE	74	106	660	1	0	0
				1D[l]	0	9					13TY	13	2D[l]	49					
													22BD	253					
													2AD	2					
													6PT	9					
													20TY	23					
Mississippi‖	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Missouri	1TY	0	26	0	0	0	2TY	33	0	0	0	0	0	0	3	59	0	0	0
Montana¶	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nebraska	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nevada	1GE	0	±40	1TY[m]	0	5	0	0	1GE	6	0	0	0	0	4	59	1	0	0
	1TY	0	8																
New Hampshire	0	0	0	0	0	0	0	0	0	0	0	0	SpTY	6	—	6	0	0	0
New Jersey**	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
New Mexico	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

New York	1GE[n] 17GE 2BD 1TY[n]	1 2 0 1	±34,000 712 210 6	1GE[o]	1	109	4GE	288	29GE	1,172	3GE 3BD 2TY	89 128 6	34GE 4BD 3PT	1,055 57 105	104	37,937	17	1	0
North Carolina††	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
North Dakota	0	0	0	SpTY[p]	0	4	0	0	SpTY	1	SpTY	8	SpPT SpTY	2 23	—	38	0	0	0
Ohio‡‡	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1182GE 297BD 4AD 21PT 346TY	0	0	0
Oklahoma	0	0	0	0	0	0	1TY	26	0	0	0	0	SpBD SpAD SpTY	625 24 456	1	1,131	0	0	0
Oregon	1GE[q]	1	±1,000	0	0	0	0	0	1TY	7	0	0	0	0	2	1,007	1	0	0

|| No outbreaks reported during 1940.

¶ No outbreaks reported.

** No water-borne outbreaks reported during 1940.

†† No water-borne outbreaks reported in 1940.

‡‡ No outbreaks reported in 1940. Total of Ohio cases is not added in summary.

[j] Occurred when water was not treated. Epidemic terminated by chlorination of water supply.

[k] Drank from well subject to contamination by surface water.

[l] (D denotes dysentery of unknown type.) Nine cases of possibly water-borne dysentery drank from well containing coliform organisms.

[m] Water supply definitely bad; no definite indication that water supply caused infection.

[n] Gastro-enteritis and typhoid resulted from pollution through cross-connection between polluted fire supply and portion of Rochester, N. Y., public supply system.

[o] 67 per cent of cases occurred among pupils and teachers of one school. Numerous cases were secondary in families of primary cases. At climax of outbreak, no coliform organisms found in five samples from wells and distribution system. No common vector other than water implicated.

[p] Three cases from raw river water and one case from melted river ice.

[q] Outbreak not reported until five days after onset. About half of town of 3,000 affected. Believe surface pollution, after very heavy rains, of spring which are source of public supply.

Relation of Public Water Supplies to the Occurrence of Intestinal Diseases From All Causes

See beginning of tabulation for key and other notes

STATES & PROVINCES	DEFINITELY WATER-BORNE			POSSIBLY WATER-BORNE			MILK-BORNE		FOOD-BORNE		DIRECT CONTACT		UNKNOWN VECTOR		TOTAL		FOOTNOTE		
	Outbreaks		Total cases	Outbreaks		Total cases													
	Total	P.W.S.[a]		Total	P.W.S.[a]		Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	b	c	d
Pennsylvania	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rhode Island	0	0	0	0	0	0	1TY	5	2GE	164	1TY	4	1TY	4	5	177	0	0	0
South Carolina	0	0	0	1GE[r]	1	±300	1GE	5	1GE	±500	—	—	—	—	3	805	0	1	0
South Dakota§§	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tennessee	0	0	0	0	0	0	1GE	9	3TY	22	0	0	1BD	40	5	71	0	0	0
Texas	1TY	1	10	1AD[s]	1	4	0	0	1GE	5	0	0	2BD	100	13	163	0	0	0
				1TY[s]	0	3			1TY	8			6TY	33					
Utah‖‖	—	—	—	1BD[t]	1	150	—	—	—	—	1TY	3	2BD	10	6	173	0	0	0
													2TY	10					
Vermont	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Virginia	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Washington	1TY	1	4	0	0	0	0	0	3TY	12	0	0	1GE	130	7	266	0	0	0
													1BD	35					
													1AD	8					
													SpTY	77					
West Virginia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wisconsin	0	0	0	0	0	0	0	0	0	0	0	0	SpGE	some	—	41	0	0	0
													SpTY	41					

Wyoming	0	0	0	SpPT	0	2	0	0	0	0	SpBD	2	SpGE	2	2	40	0	0	0
				SpTY	0	12					SpTY	10	2BD	12					
Provinces																			
Alberta	1GE	1	—	—	—	—	—	—	—	—	—	—	—	—	3	+7	1	—	—
	2TY	0	7																
Br. Columbia	—	—	—	—	—	—	—	—	2GE	255	SpPT	1	SpPT	4	2	262	0	0	0
											SpPT	2							
Manitoba	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
New Brunswick	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nova Scotia	0	0	0	0	0	0	0	0	0	0	3PT	3	0	0	15	19	0	0	0
											12TY	16							
Ontario	0	0	0	1TY[u]	1	6	0	0	0	0	0	0	0	0	1	6	0	0	0
Pr. Edward Is.	—	—	—	—	—	—	—	—	—	—	—	—	1GE	3	2	4	0	0	0
													1TY	1					
Quebec	2GE	0	65	1TY	1	6	2TY	33	0	0	2TY	33	0	0	14	395	0	0	0
	1BD	1	150																
	6TY	6	108																
Saskatchewan	—	—	—	2TY[v]	0	21	—	—	—	—	—	—	4TY	19	6	40	—	—	—

§§ Believe Gastro-Enteritis occurred, but no definite information.

‖‖ No definitely water-borne outbreaks reported.

[r] State Board of Health not notified until a week after onset.

[s] In amoebic dysentery outbreak, coliform organisms found in water system but not in well. No other common vehicle implicated. In typhoid epidemic, sanitary conditions generally unacceptable. Several small household systems in village involved. Water was only apparent common source.

[t] Source of supply is infiltration area with tile laid 1 to 4 ft. deep. Analyses have repeatedly shown contamination. Cases widely distributed about town. Fruitpickers had access to area and human fecal matter was discovered on infiltration area after outbreak.

[u] Large fire left chlorinator inadequate for disinfecting increased volume.

[v] In domestic systems.

Relation of Public Water Supplies to the Occurrence of Intestinal Diseases From All Causes

Summary of Data Reported

INTESTINAL DISEASES	DEFINITELY WATER-BORNE			POSSIBLY WATER-BORNE			MILK-BORNE		FOOD-BORNE		DIRECT CONTACT		UNKNOWN VECTOR		TOTAL		FOOT-NOTE		
	Outbreaks			Outbreaks															
	Total	P.W.S.[a]	Total cases	Total	P.W.S.[a]	Total cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases	b	c	d
Gastro-enteritis (GE)	26	7	39,721	9	8	666	6	302	55	2,945	3	89	84	1,521	183	45,247	27	5	0
Bacillary Dysentery (BD)	3	1	360	1	1	150	2	200	3	43	13	296	34	507	56	1,556	—	—	—
Amoebic Dysentery (AD)	—	—	—	1	1	4	—	—	—	—	—	—	3	10	4	14	—	—	—
Dysentery, unknown type (D)	—	—	—	1	—	9	—	—	—	—	—	—	2	49	3	58	—	—	—
Paratyphoid (PT)	—	—	—	—	—	—	—	—	1	29	5	9	11	148	17	186	—	—	—
Typhoid Fever (TY)	19	9	284	8	2	55	8	118	10	71	33	83	35	100	113	711	—	—	—
Total (including no sporadic cases)	48	17	40,365	20	12	884	16	620	69	3,088	54	477	169	2,338	376	47,772	—	—	—
Total sporadic cases—all types	—	—	—	—	—	18	—	—	—	1	—	29	—	1,562	—	1,610	—	—	—
Grand Total																49,382	—	—	—

system through a cross-connection. The cases reported were 6 of typhoid and an estimated 34,000 of gastro-enteritis.

It will be noted that the tabulation under discussion contains footnotes which briefly explain some of the circumstances surrounding the water-borne epidemics. A more comprehensive review of all the replies received indicates that the great majority of the outbreaks were caused by water containing coliform organisms or by supplies with obvious sanitary defects. There are a few exceptions and these will be mentioned because of the current interest in obscure outbreaks. Two outbreaks of gastro-enteritis occurred in Indiana at about the same time—one at Semour with 168 cases, and one at Mitchell with 67 cases. Both cities have small filtration plants taking water from the East Fork of White River. Such samples as were examined were satisfactory, but the chlorine demand of the water is known to have increased downstream. New York reports an outbreak of gastro-enteritis involving 109 cases which occurred at Mayville. Some 67 per cent of the cases were pupils or teachers in one school and their immediate families. The duration of the outbreak was one month and two sets of water samples taken during this period were negative for coliform organisms. No pathogenic organisms could be isolated from fecal specimens examined. The well water supply may have been subject to intermittent pollution. Another obscure outbreak of some 300 to 500 cases of gastro-enteritis was reported from Great Falls, S. C. The State Department of Health was not notified until a week after the onset, but it is probable that the water supply was contaminated by a cross-connection in the boiler room of a textile plant.

In general, the returns from this year's questionnaire are similar to those of previous years. A number of states continue to submit very complete data, others can furnish only partially complete data, and some frankly state that they lack the facilities and personnel to conduct investigations of intestinal outbreaks.

It would seem that little can be gained by further statistical study of this subject by committees of this Association pending the development by health agencies of more precise statistics of intestinal disease in general and gastro-enteritis in particular.

In the light of the investigation which this committee has carried on for several years it can only repeat the conclusions stated in previous reports that, notwithstanding the occurrence from year to year of a few obscure intestinal outbreaks, the mass of the evidence

supports the effectiveness of water treatment procedures and water quality standards, *provided these procedures are properly applied and controlled.*

George D. Norcom, *Chairman*
Charles R. Cox
A. F. Mellen
W. M. Wallace
L. F. Warrick

Editorial Note: When this report was presented, the Committee requested that it be discharged. The suggestion was made that the collecting of statistical data upon a year to year basis was not truly a research committee responsibility. The Water Purification Division expressed appreciation for the Committee's work and dissolved the Committee.

ABSTRACTS OF WATER WORKS LITERATURE

Key. 31: 481 (Mar. '39) indicates volume 31, page 481, issue dated March 1939. If the publication is paged by issues, **31:** 3: 481, (Mar. '39) indicates volume 31, number 3, page 481. Initials following an abstract indicate reproduction, by permission, from periodicals as follows: *B. H.—Bulletin of Hygiene (British); C. A.—Chemical Abstracts; P. H. E. A.—Public Health Engineering Abstracts; W. P. R.—Water Pollution Research (British); I. M.—Institute of Metals (British).*

DISTRIBUTION SYSTEMS—CONSTRUCTION AND MAINTENANCE

Fibers Used in Water Practice. J. A. de Graaf. Water. (Neth.) **25:** 21 (Feb. 7, '41). *Excerpts.*

Among materials used by water technicians are some produced from fibrous substances. A brief summary is given on the production of the fibers, how they are obtained, their characteristics and use. In accordance with their source they may be divided into the following groups:

- *A. Animal fibers* (hair, wool, natural silk, etc.)
- *B. Vegetable fibers*
  1. Seed or fruit hair (cotton, kapok, etc.)
  2. Leaf strands (manila, sisal, cantala, henequén, etc.)
  3. Leaf fibers (flax, hemp, jute, rameh, etc.)
  4. Fruit fibers (cocos, luffa, etc.)
  5. Little or not changed plant parts (straw, rotan, bamboo, rushes, sea grass, raffia, etc.).
- *C. Artificial* [or metamorphosed] *fibers*
  1. Artificial silk
  2. Paper twine
  3. Wood fibers (excelsior)
- *D. Mineral* [*sic.*, in original] *fibers*
  1. Asbestos
  2. Glass and sinter wool
  3. Metal threads

With the exception of a few mineral fibers used for packing, insulation, etc. all fibers used belong to Types 2, 3 and 4 of Group B. These fibers differ in general from the better known materials such as cotton and wool because they are more stretched or extended, harder, stiffer and less elastic. The principal constituent is cellulose, while they have a more or less woody character. The fibers commonly known are composed of small fibers, called "elementary fibers," consisting of long, hollow cells connected by a glue-like material. At ordinary temperatures the glue is rather hard. The length of the elementary fibers is, in most cases, at most a few centimeters. The water man is primarily interested in flax, hemp, jute, cocos and rameh, while, in times of stress, other fibers such as sisal may be used.

After treatment, the fibers look much alike, especially certain kinds of hemp, flax and jute. The structure of the elementary fibers is quite different, as can be seen under the microscope. Several other fibers, such as sisal, cantala or manila, show considerable conformity. It is difficult for the buyer to determine whether the proper material is received. This difficulty is increased by the confusion of names applied to the fibers. For instance, New Zealand hemp, which is not a hemp, is also sold under the name New Zealand flax, though it has nothing to do with flax. Table 1 gives the names, synonyms, source and plant family of the best known and most commonly used

fibers. The last column indicates family relations between the various plants.

A brief description of the origin, production and occurrence of the fibers used in the water field may be helpful. [Following description has been condensed.]

Flax. Better qualities used for mfr. of lace, damask and linen, and poorer materials for thread. Best flax comes from Ireland and Belgium, but Russia, France, Austria, India and America produce large quantities. Flax is an annual plant having one stem—height to 3′—blue flowers, and linseed oil obtained from its seeds. Stem consists of tube filled with marrow surrounded by woody layer. Around woody layer is bark containing the fibers. After ripening, flax is bundled, dried and the seed removed; separation of fibers followed by retting (rotting and washing), breaking (cracking of stems), beating (removal of woody material and separation of fiber), and hatchelling (splitting of bundles, removal of impurities by combing, and separation of short and long fibers). Offal or combings is oakum.

Hemp. Value is less than of flax and more labor required. Grown mostly in Russia, America, Spain, Italy. Length often 5′-8′; fibers coarser than flax; finest fibers come from Italy, so-called Venetian hemp, and cannot be distinguished by feel or eye from flax, only by microscopic exam. Greatest use for twine, cables, tow. Treatment to produce fiber very similar to flax.

Jute. Primarily from Asia, especially British India. Stems 10′-15′; subjected to partial rotting, stripping of bark by hand after treatment with water and oil. Fiber is fairly tough, much coarser and less elastic then flax or hemp. Fine fibers look much like hemp and flax, difficult to distinguish. By weathering, compactness is soon lost, especially when damp; unfit for thread, excellent for bags.

Rameh. Rameh, ramie or China grass comes from plant belonging to nettle family; native to South Asia and China. Separation of bark and fiber very difficult, so that fibers are rather expensive. Fiber is fine, compact, glossy. Can replace flax in many instances.

TABLE 1

TECHNICAL NAME	SYNONYM	PLANT SPECIES	PLANT FAMILY
Hemp	Hennip	Cannabis sativa	Moraceae
Flax	—	Linum usitassimum	Liaceae
Jute	—	Corchorus capsularis	Tilieae
Rameh	Ramie, china grass	Boehmeria nivea	Urticaceae
Cocos	Coir, klapper fiber	Cocos nucifera	Palmae
Abaca	Manilla hemp, koffo	Musa textilis	Musaceae
New Zealand hemp	New Zealand flax	Phornium tenax	Liliaceae
Ambari	Deccan hemp, Gambo hemp, Java jute	Hibiscus cannabinus	Mobraceae
Aloë	Mauritius hemp	Furcroea gigantea	Amarylidaceae
Sunn	Bombay hemp	Crotalaria juncea	Leguminosae
Desi jute	Jute	Corchorus olitorius	Tilieae
Chingma	China jute	Abutilon theophrasti	Mobraceae
Sisal	Java Sisal	Agave sisalana	Amarylidaceae
Henequén	Mexican sisal	Agave fourcroydes	Amarylidaceae
Cantala	Manila	Agave cantala	Amarylidaceae
Bahia Piassave	Bass	Attalea funifera	Palmae
Cotton	—	Gossypium spec.	Bombaceae
Java kapok	Kapok	Ceibapentandra	Bombaceae
English Indian kapok	—	Bombax malabaricum	Bombaceae

Cocos. Cocos, coir or klapper fiber comes from fruit of cocospalm. Palm grown in few countries produce fiber fit for industry; poorer material used for mats, brushes and oakum; better for thread. After splitting of ripe fruit and removal of meat, bark is buried in mixture of fresh and salt water, causing softening of porous mass between fibers. After about 2 months material is hammered and fibers separated.

Sisal. Sisal is leaf fiber of agave. Leaves are retted, pressed, shaken out and dried. Fibers are very strong, used for white twine which is strong, but loose and hairy. Comes from Mexico, East Africa, Netherlands India and Hawaiian Islands. Closely connected with henequén and cantala or manila; difficult to distinguish without microscope.

Packing Material for Couplings. Fibers, in form of loose bundles, are used after greasing. Best material for couplings is Italian hemp with long, fine, strong fibers. A good quality flax can be used, although compactness is less.

Twine or Lording. Good twine requires a soft fiber, free from woody material. Flax, hemp and jute are suitable. Jute is cheaper, but flax is valuable under certain conditions. From 3 to 4 bundles of fiber are twined and sold as twine or lording. Twining allows alignment of fibers, while strength and hardness depend upon type of fiber and number of twists. Fibers from sisal, cantala or manila unfit for good twine. When couplings, which have remained in ground for long time, are opened, will be seen that large amount of twine has disappeared, while another part has slimy feeling, is black and can easily be broken. Often, layer immediately behind lead is still intact. Investigations have shown that twine, consisting almost exclusively of organic material, is source of food for bacteria and higher organisms. This may be considered as objectionable. To alleviate this trouble, City of Amsterdam uses as first layer a specially prepared twine, soaked with a special tar product, which is non-poisonous and produces no taste, odor or color. Tests with cotton (Jour. A.W.W.A. **26**: 743 ('34)) have been made; general utilization unknown to author.

Fire Hose. According to Dutch specifications fire hose must be made from: pure hemp, pure flax or pure rameh. Hemp and flax can be lined with rubber, rameh always with rubber. Also used for flushing. Life of ordinary hemp hose limited. Extensive expts. made in Amsterdam during '38 and '39 with hose of different materials to determine what type most economical. Tests were made with ordinary hemp hose, oiled (treated like fish nets) hose and rubber lined rameh hose. All hose treated in same way and used under similar conditions. Average life of ordinary hemp hose in constant use was 40 days, oiled slightly longer, while rameh hose lasted 240 days. Price of rameh hose was 4 times higher than hemp hose.

Tissues Used for Protection of Piping. For so-called heavy protection of steel pipe soaked jute, soaked cocos cloth or soaked asbestos felt must be used according to recommendations. Felt made from mineral asbestos fiber should be soaked in one of petroleum distillates. Formerly used and most primitive method for protection is surrounding pipes with strip of jute immediately after layer of asphalt or tar product has been applied to pipe, followed by smearing more asphalt or tar on top. Several of such layers complete protection. Number of such treated pipes used "as bridge pipes" were removed after two and more decades. After removal of layers, which appeared to be hanging loose around pipes, little corrosion or harm could be detected. Only at places where covering had been damaged was strong pitting evident. Such loose coverings easily damaged.

Some microphotographs of elementary fibers of flax, hemp, jute, rameh, cotton and sheep wool shown. Elementary flax fiber looks like long tube separated by cross lines, which have been slightly moved in relation to each other to show "nodes" or "knots." In middle of tube, double dark line is visible. Microscopic view of hemp does not show double line in center of tube, but less clearly defined lines, parallel to cell wall. Nodes are less sharp. Cells of jute fiber are larger and coarser than of flax and hemp; cell walls are thicker. Rameh shows

local thickening of cell wall; this characteristic is sufficient for identification. Cotton fiber shows clearly flattened plant cells with thickened edges, which by evaporation of cell liquor twist like corkscrews. Sheep wool fiber is scale-like, easily distinguished from cotton or other animal hair.

Substitution Products. J. H. Schneider. Water (Neth.) **25:** 9 (Jan. 10, '41). In connection with difficulty of obtaining lead for tightening joints, expts. conducted with other materials. Results show that rubber of good quality can be used; aluminum and "sinterit" (sponge-like iron mass, produced by heating iron powder low in carbon to 1200–1300°C. and coking in reducing atmosphere) are not fit, since excessive leakage will result. Expts. with re-use of old lead shows it incapable of withstanding pounding or jolting, but by addition of 1% antimony, expansion and bending greatly increased, giving fair joint. Steel should be substituted for lead and copper piping; corrosion of couplings can be reduced by thin sheet of copper or with aid of so-called "Kuprema" tubes, consisting of 0.2–0.3 mm. thin copper kernel or heart surrounded by specially treated paper. Miopalm, artificial resin from coal, glass-hard at low temp., but kneadable at 80°C., has no value. Glass and procelain have value only in special cases. Alloys with aluminum content between 4 and 25%, copper 0.5 and 1.2% and remainder zinc, appear to produce good results. Substituting aluminum for lead results in corrosion troubles unless layer of asphalt present. Author states: "Word 'ersatz' avoided, because, with variation on French proverb, 'In the house where substitution products are used the rope is not mentioned.' "—*Willem Rudolfs.*

Chlorination of Water Mains. L. H Scott. Southwest W. W. Jour. **23:** 2: 18 ('41). All jute or hemp steam sterilized and dispensed through small hole in top of container; thus keeping yarn clean on job. Often, cost of conditioning second-hand pipe for service and sterilization of pipe in ground equals cost of laying new pipe. Most effective chlorination to use heavy dosage under pressure for 12 hr., followed by continuous chlorination with dosages sufficiently high to insure safe water. Difficult situation handled by injecting copper sulfate along with chlorine.—*O. M. Smith.*

Distribution System Diagnosis. Edgar K. Wilson. Eng. News-Rec. **126:** 967 (June 19, '41). Elimination of weaknesses calls for 3-point exam.: (1) investigation of pump efficiency; (2) survey of distr. system leakage; and (3) long-range study of distr. system needs. Defective valves in reciprocating pumps or worn impellers in centrifugal pumps should be repaired to restore efficiency. Tests often indicate that pumps not adapted to service on which they are used and that considerable economy and more satisfactory performance will result from changing to pumps designed specifically for service required. Pitometer measuring devices may be employed to check both meter and pump performance. Relation between total daily consumption and min. night rate important, unduly high night flows indicating leakage or waste Distr. system should be divided into small districts by closing boundary valves and 24-hr. consumption in each measured by pitometer. Each block then closed off for short period at night and pitometer changes observed. Blocks showing abnormal flow require further investigation. Elimination of waste defers capital replacements, relieves load on treatment facilities and reduces pumping costs. Important by-product benefit of waste survey is inspection of valves, 80–90% being operated during survey. Unfortunately, in many instances, little foresight used in planning for future requirements. Systems should be analyzed as whole, then studied in sections. Primary requisite is analysis of population trends and probable shifts in relation to demand on arterial mains. Fire flow tests invaluable and all important feeder mains should be investigated for excessive loss of head. Peculiar situations in regard to direction as well as volume of flow often revealed by study of arterial system.

Master plan of improvements should be drafted and used as basis for work program.—*R. E. Thompson*.

Correcting Ills in a Water Distribution System. R. E. McDONNELL. Southwest W.W.J. **22**: 11: 17 ('41). Emphasis placed on designing of distr. system improvements rather than that of guessing at solution. Examples given showing how Hardy Cross method of analysis provides for all guessing to be done on analysis sheets. Changes as determined by method made at no. of large inland cities.—*O. M. Smith*.

Maintenance of Water Works Distribution System. C. G. ROUTLEDGE. Can. Engr.—Wtr. & Sew. **79**: 6: 56 (June '41). Toronto divided into 3 districts for distr. system maintenance and service installation. Emergency truck with 2 men and repair crew of 4 men assisted by 2 for operation of truck or compressor always on duty. In addition, continuous emergency service by 2 men and truck maintained in eastern dist. yard. Emergency truck equipped with plans showing location of valves and no. of turns required to effect closure, and with mechanism for operating valves and pumps. Large valves inspected, oiled and operated annually. Fire hydrants inspected every 3 wk. and more frequently during very cold weather. Inspectors carry aquaphones for leak detection. Frozen hydrants thawed with steam from portable boiler. Main maintenance bldg. occupies area of 71,000 sq.ft. and comprises general offices, pattern, machine, blacksmith, meter testing and motor truck repair shops, garage and general stores.—*R. E. Thompson*.

Directions for Protection From Frost and for the Thawing of Frozen Water Lines. *D.V.G.W. Standards*. Gas u. Wasserfach. (Ger.) **84**: 71 (Feb. 2, '41). Steam has to be produced in boiler of sufficient strength and size to give continuous stream of from 1 to 7 atm. pressure. Superheater recommended. Steam introduced through copper, lead or steel pipes or by use of reinforced rubber or flexible metal pipes. Steam to be conducted to face of ice and melting water removed. For thawing with electrical current, 20 to 40 v. and 100 to 600 amp. recommended. Pipe in soil should not receive less than 200 amp. Transformers should be built to allow selection of several primary and secondary current conditions. Constant control necessary by electrical instruments and thermometers on pipes. Open outlet valve before starting current and shut off current as soon as water starts running, then continue thawing with water current. Do not shut off water too early. Many precautions necessary mentioned. Several auxiliary methods described and warning not to use open fires or soldering flame. Article richly illustrated.—*Max Suter*.

Underground Services Mapped for Emergency Needs. STEPHEN KEARNEY. Eng. News-Rec. **127**: 31 (July 3, '41). Mapping of underground structures and utilities in Lowell, Mass., undertaken recently as W.P.A. project. Sectional maps, scale of 50′ to 1″, used as basis for survey, different structures being indicated by various colors. Few of most important intersections mapped on scale of 20′ to 1″, both location and depth being indicated. Elaboration of intersection maps and preparation of tracing of entire city on scale of 500′ to 1″, on which can be spotted vital works such as reservoirs, pumping stations, hospitals, gas tanks, etc., now under way.—*R. E. Thompson*.

Cost of 6-Inch Water Main. ANON. W. W. Inf. Exch., Can. Sec., A.W.W.A. **4**: B: 1: 1 (Aug. '41). Answers (81) to questionnaire relative to cost of laying 6″ Class B water mains summarized under following headings: depth, width and cost of excavation; material cost; laying and miscellaneous; backfilling; total. Total cost varied from $1.03 to $5.68 and averaged $2.21 per ft.—*R. E. Thompson*.

Floating a Pipeline Into Place. HARRY U. FULLER. Eng. News-Rec. **127**: 375 (Sept. 11, '41). Method used in laying 3,000′ of 8″ steel pipe in Portland Harbor in previously dug trench 40′ below sur-

face described. Employment of divers would have been slow and expensive, as temp. of sea water below 32°F. Line jointed above water with Dresser couplings, reinforced by cadmium-plated bolts through 2 lugs welded on each end of each 40′ length of pipe. Strongback then fastened on top of pipe at each joint and, on top of strongback, 2 empty steel oil drums lashed to provide buoyancy. Admission of 5 gal. of water into each drum adjusted buoyancy to point where line tended to sink. Middle section of line lowered first and line kept full by admitting water through 2″ gate valve in cap at one end while other end was being extended by successive lengths of pipe. This permitted close control of buoyancy in conjunction with oil drum floats. After line placed in trench, drums punctured with steel point. Line in operation more than 6 mo. and tests show no leakage.—*R. E. Thompson.*

Age of Water Mains. ANON. W. W. Inf. Exch., Canadian Sec., A.W.W.A. **4:** C: 1: 1 (Mar. '41). Tabulation of length of time that oldest cast-iron water mains have been in service in various Canadian municipalities. Length of service ranges up to max. of 97 yr. Estimates of life of these mains vary through wide range up to max. of 300 yr.—*R. E. Thompson.*

More Capacity With Clean Mains. CLINTON INGLEE. Eng. News-Rec. **126:** 963 (June 19, '41). Cost of cleaning mains but fraction of carrying charges on capital for new or supplementary piping. In addition, work can be done in fraction of time—particularly important at present time when speed essential. Max. delivery capac. desirable at any time for fire fighting service but more so in wartime when water may have to be conveyed through long series of mains to provide service beyond a break. Detailed instructions should be prepared now for blocking off of damaged areas with min. interruption to service. Examples of surprising economies in power required for pumping, which may be effected by main cleaning, outlined, and tabulation included showing power required for pumping through, 1,000′ of 6–24″ pipe before and after cleaning. Cleaning procedure is to make 2 openings in main, one for insertion of machine and other for ejection of dirt and machine through 45° bend and riser. Machine propelled by water pressure or pulled through main by means of cable. Some water allowed to pass machine to carry ahead of it dirt and incrustation removed. Interruption to service in any district need not exceed 5–7 hr. and, in case of emergency, mains can be temporarily reconnected in short time. Rehabilitation program can be carried out in days instead of weeks or months.—*R. E. Thompson.*

Internally "Sleeving" a 36-Inch Water Main. A. M. MOON. Surveyor. (Br.) **99:** 267 (Apr. 18, '41). 36 internal diam. gravity main, laid under public way, and running through hill at considerable depth, sustained extensive damage. Found, by crawling through line that more pipes broken at some considerable distance from repair site. Preliminary inspection had already shown that main was neither straight nor level. At worst spot main was $3\frac{3}{4}$″ off center and $3\frac{1}{4}$″ out of level. Therefore decided that only satisfactory type of repair available was to "sleeve" damaged portion with steel tubes, using as large diam. as possible. Most suitable tubes available were "nominal" 30″ diam. bitumen-coated, double spigot, steel pipes, with actual outside diam. of $32\frac{1}{4}$″. To obtain as easy passage as possible (of steel main through cast-iron pipe) 36″ main cleaned. Some flexibility introduced at joints (of steel pipe) by use of butt straps, 12″ wide by $\frac{3}{8}$″ thick. Finally decided to make use of small trolleys running in pipe invert. 56′ of tube entered by means of pulley tackle and screw jack. Grouting of space between sleeve and main by machine working at a pressure of 50 lb. per sq.in. Grout in form of neat cement with sand sprinkling.—*H. E. Babbitt.*

Water Pipe Leaks Plugged With "Jelly." HERMAN H. EYMER. Eng. News-Rec. **127:** 371 (Sept. 11, '41). 24″ cast-iron river crossing, 1,400′ long, with 128 oakum-lead bell-and-spigot

joints, when laid in Saginaw, Mich., in '30, showed initial test leakage of 421 gal. per hr. After 2 yr. leakage was 200 gal. per hr. and city refused to accept line from contractor. Test with air pressure indicated numerous leaks, bubbles rising to surface along line of main. After demonstration by Hans A. Reimers, former chemist of city water dept., main filled with solution of sodium silicate and aluminum sulfate, with some powdered asbestos to act as filler, and pressure of 15 lb. applied to balance outside hydrostatic pressure. Thereafter, pressure raised at rate of 5 lb. per hr. until pressure of 85 lb. reached. Gradual increase in pressure enabled solution to "set" in leaky places without excessive loss of solution. 5 hr. after max. pressure reached, pressure remained constant, showing leaks had been sealed. Pressure maintained overnight and soln. displaced with soln. of calcium chloride. Test pressure of 65 lb. showed no apparent leakage. Finally, calcium chloride flushed out with water. Unfortunately, severe water hammer caused by sudden closing of valve caused some leaks to reopen. 30-day check test made 2 wk. later, however, showed leakage to be constant at 5.5–7.5 gal. per hr. and test made 1 yr. later showed that leakage had again fallen to zero. More detailed account of method may be found in U. S. Patent 2,188,311, issued to Hans A. Reimers.—*R. E. Thompson.*

Extra Valves Minimize Water Interruptions. ANON. Eng. News-Rec. **126:** 966 (June 19, '41). W.P.A. workers in New York City closing up gaps between shutoff valves in old lines and installing valves at 1,000′ intervals in new mains. Roundabouts, or connections between mains through which water may be bypassed in case of break, also being installed to minimize service interruptions.—*R. E. Thompson.*

Novel Construction of a Large Venturi Meter. LEON SMALL. Civ. Eng. **11:** 550 (Sept. '41). Montebello Filtration Plants, Baltimore, Md. went into service in '15. Additional unit added 13 yr. later, but no provision for metering 108″ conduit, carrying finished product from plants to distr. system. After location for meter selected, 54″ steel bypass constructed to carry part of flow around site during construction. Before possible to allow water into bypass, 108″ conduit temporarily closed down and access to interior gained by construction of manhole. After section of conduit isolated, all construction on meter carried out through access manhole. When upstream throat ring assembled and alined, various screen rings fixing contour of cones fastened in place by adjustable screws. Closure of access port accomplished by fitting curved bronze plate into opening while inspection personnel inside conduit. Replacement of plate made immediately after release of inspectors. Plate then bolted in place and remainder of entrance shaft filled with reinforced concrete plug.—*H. E. Babbitt.*

Elevated Steel Water Tank Takes Ride to New Site. ANON. Eng. News-Rec. **127:** 179 (July 31, '41). Moving of elev. tank in upright position distance of $3\frac{1}{2}$ mi. one of spectacular undertakings involved in shifting entire town of Shawneetown, Ill., from flood-ravaged location on Ohio R. to high ground. 80,000-gal. tank 132′ high and weighs 60 tons. 36″ riser pipe moved intact with tank. Tower loaded on carriage consisting of 4 sets of heavy-duty 4-wheel dollies tied together by heavy timber framing. Motive power provided by 2 crawler tractors. Journey included 4 corners and 1 railroad crossing.—*R. E. Thompson.*

Uses Ice Cubes to Seat Water Tank on New Foundation. ANON. Ry. Eng. & Maint. **37:** 482 ('41). Southern Pacific R.R. recently erected 200,000 gal. flat-bottomed steel tank, 35′ diam., at Roseville, Calif. Bottom and first ring fabricated on cribbing for painting and water test. When lowered, 300 lb. cakes of ice spaced uniformly around outer edge and cribbing removed. Steel settled uniformly on to sand cushion by following morning. Only precaution necessary to protect ice cakes against direct rays of sun to prevent uneven melting.—*R. C. Bardwell.*

SERVICES AND METERS

New York Public Service Commission. Re *Rules, Regulations and Practices of Water Works Corporations.* Pub. Util. Fort. **34:** 116 (Aug. 15, '40). Appearances: counsel and engrs. for Com., and counsel and officials of 31 cities and/or water companies in N. Y. State. Consideration of and rules adopted regarding installation of service pipes and main extensions. Past practices of different water utilities reviewed. In two proceedings extending over a period of 3 yr. about 400 pp. of testimony taken. In addition, briefs, memoranda and letters submitted were examined. Further revision made and order adopted. Rules relating to the installation of mains, services, connections, and facilities and extensions of water works corps.: (1) All water works corps. to furnish and install, at their expense, all mains, services and other facilities within limits of any street. (2) Upon written application of owner or occupant of any property within 75′ of any main, water works corp. shall install all facilities required for delivery of water, and pay all costs incidental thereto. (3) If applicant for water is more than 75′ away, he shall pay a surcharge of 9% per year on cost of pipe over 75′. If main is larger than 6″, 9% shall be paid on estimated cost of 6″ main. If more than one customer, 9% surcharge prorated, and if number of customers multiplied by 75′ exceeds length of extension, or total revenue exceeds ¼ cost, no surcharge shall be made. (4) Cost of service pipe without street limits paid by consumer. (5) If service is not immediately used, consumer will pay. He is, however, entitled to a refund, less depreciation, at 3% per annum for time pipe was installed. (6) All water works corps. solely responsible for maintenance and replacement of all mains and facilities within street limits, except service pipes less than 2″ diam. and over 75′ long, heretofore installed and privately owned. (7) Every water works corp. shall include in its tariff schedules provisions carrying out the requirements of these rules and regulations. (8) If any water works corp. considers any of foregoing rules unjust, it may make application for modification setting forth facts and circumstances.—*Samuel A. Evans.*

Standards for the Calculation of Pipe Sizes in House Installation. Anon. Gas u. Wasser. (Ger.) **83:** 345, 359 (June 20, 27, '40). Standards deal only with calculation of pipe size, based on Lang's formula for loss of head in house installation. Formula is

$$\frac{h}{1} = \lambda \frac{1}{d} \frac{v^2}{2g}$$

where

$$\lambda = 0.009 + \frac{a}{\sqrt{d}} + \frac{0.0019}{\sqrt{vd}}$$

Value of a depends on type of pipe, being $a = 0.005$ for lead and copper pipes, 0.012 for steel pipes and 0.018 for cast iron. Formula is complicated and was simplified to

$$\frac{h}{1} = a \frac{z}{d^b}$$

for which tables are given. Amount of water to be furnished depends on number and kind of outlets and their probable common use. Directions are given for estimation of water requirements. Limits are fixed for allowable loss of head and examples of calculation included. No consideration to backsiphoning given.—*Max Suter.*

On the Systematic Check-Up of Water Supplies in Buildings. Eduard Baese. Gas u. Wasser. (Ger.) **83:** 310 (June 29, '40). Regularly repeated check-ups of water supply in bldg. are made in Dresden to discover leakage, to determine suitability of meter and to check backsiphoning. No. of meters checked in bldgs. varies from 17 to 62% of those installed, one operator being able to make from 1,300 to 1,600 checks per yr.

About 35% of meters checked showed errors over 5% and had to be taken to shop. Leakage was found in ave. of 43% of bldgs. On total aves. no direct relation from yr. to yr. existing between no. of bldgs. with leakages and no. of satisfactory meters, as age and type of meter have influence. Data given show that volumetric meters superior to velocity meters by giving better results even in presence of leakage. Consideration of cost and scope of bldg. leaves, however, justified use of velocity meters in many cases.—*Max Suter*.

Experiences in Protecting Water Pipes From Frost. F. J. Reny. W. W. & Sew. **87:** 586 (Dec. '40). Meter protection at Portland, Me. comprises installation in wooden vault or in kitchen of home, where warm basement is unavailable. 5½′ of cover eliminates service line freezing. Rubber insulation of services has proved practical where use of water only occasional. Wooden board cover for shallow services is surprisingly effective. Satisfactory insulation for bridge crossings described. Freezing in submarine line prevented by warming input water. Submarine pipes exposed to sea water should be trenched and given adequate cover.—*H. E. Hudson, Jr*.

Systematized Record for Service Box Locations. Anon. Eng. Cont. Rec. **54:** 15: 15 (Apr. 9, '41). During '40, recording of locations of all curb boxes for water services in all municipalities coming within jurisdiction of Windsor Public Utilities Com. completed. Distances from boxes to curb and to bldgs. measured and recorded in ready-reference record book. Book of heavy post binder type, with pages 10″ x 14″, 3½″ thick and contains record of 20,307 service box locations. Index sheets at front show streets in alphabetical order and range of house numbers to be found on each page. In back are maps of distr. system, street system and house numbering layout. 13 copies made, including 1 for each service truck. Original sheets typewritten on very thin tracing paper and carbon-back process used to make direct-line white prints. Any box can be located in 2 min.—*R. E. Thompson*.

Kinds of Service Pipe Used. Anon. W. W. Inf. Exch., Can. Sec., A.W.W.A. **4:** C: 7: 19 (Sept. '41). Size of domestic services and kind of pipe used in Canadian municipalities tabulated. Of 82 communities listed, 58 employ copper, 11 lead, 4 galvanized iron and 1 galvanized wrought iron, while 4 use both galvanized iron and copper, 2 lead and copper and 2 wrought iron and copper. Size varies from ½ to 2″.—*R. E. Thompson*.

Hard-Lead Pipes, Behavior in the Field, Aging and Creep. Wilhelm Hofmann and Heinrich Hanemann. Z. Metallkunde. (Ger.) **32:** 109 ('40). Investigation of defective pipes by hardness test and creep test. Term hard lead used for lead + 1 (±.25)% antimony. Pipes which had failed in service found to be in incompletely aged condition. This is due to faulty fabrication and lack of arsenic addition. Otherwise hard lead definitely superior to ordinary pipe lead. —*C. A*.

Results of Better Maintenance and Sizing of Water Meters. H. W. Griswold. J. N. E. W. W. A. **52:** 164 (June '40). Factors having most effect on cost and efficiency of small meter maintenance are: (1) frequent inspection; (2) prompt removal and replacement of "down" meters; (3) application of efficient factory methods to testing and repair; (4) testing at regular intervals; and (5) close control of records and stock. Improved practice in Hartford directed principally to meters of 1½″ and smaller size, these bringing in 70% of total income. Four-copy work order form used with min. of copying; perpetual inventory system employed for meter stock; meters due to come out for test listed from meter reader's route book. Half-ton test truck and 1 man used for installing and changing small meters, making minor repairs and running overall accuracy-of-meter tests on high-bill complaints. Meters tested "as found' and after repair; required accuracy on 5, 16, 0.8 and 0.25 g.p.m. for ⅝″ meter is 98–102% for first 3 flows and 90% for last; 98–102% on ¾″ meter on 8, 25, 1.4 g.p.m. flows and 90% on 0.5 g.p.m.; 98–102% on 1″ meter for 13, 30, 2.2 g.p.m.

and 90% on 0.75 g.p.m. New meters of good quality, both disc and piston give, far better than required accuracy. Experience shows costs of good meter maintenance no more and perhaps little less with improved methods than formerly paid for inferior job. Yearly costs per meter for '31 and '39 inclusive are respectively (new methods in '32): $5.92, $6.35, $5.45, $6.10, $4.43, $5.13 $5.30, $4.77, and $5.02. Attempt to answer question whether improved meter maintenance is reflected in increased revenue made from 3 angles: (1) comparison of ave. revenue per person (domestic use only); (2) comparison of revenues from group of representative premises all served by ⅝" meters; (3) comparison of unaccounted for water. Method (1) indicated increase in per capita revenue from $3.50 to $3.63; (2) indicated an increase in revenue per meter of 4½%; unaccounted for water in (3) reduced from approx. 27% to 15%—7% due to tightening up of system and 5% to improved meter registration. Possibly 4% increase in revenue can be expected from improved meter registration and maintenance, other factors may modify indicated increases. Sizing of meters to meet requirements of consumer also carried out; results obtained from change from larger meter to smaller one vary widely, in some cases registration less, in others much larger. No. of interesting tables given.—*Martin E. Flentje.*

The Manufacture and Use of Light Gage Copper Tubes and Fittings for Domestic Water Service. E. Carr. Wtr. & Wtr. Eng. (Br.) **43:** 178 (June '41). Ore is mined, smelted and refined chiefly in British Empire. Refined copper used is in form of ingots having minimum purity of 99.9%. When in molten state, metal is poured into cylindrical iron molds. Billet at red heat is fed between two revolving conical rolls which roll billet over tapered steel plug on outlet side of rolls and force it into a hollow. Hollows from piercing or extrusion press are cold-worked on draw benches. Hard tubes from draw bench are fed into each end of furnace and emerge annealed but cold enough to handle. Every tube then tested to hydraulic pressure of more than 1,000 lb. per sq.in. Fittings first extruded from billets as solid rods which are then cut into short pieces of suitable weight for hot pressing. Pressings finished on automatic machines. Methods of jointing tubes evolved that do not require threads to be cut into wall of tube, so that much thinner and less expensive tubes are used, cheaper than lead and competitive with iron in cost. Copper safest metal for conveying water from public health viewpoint. Copper superior in physical qualities to any material for water service installations and less danger of burst pipes owing to frost. Other advantages are pleasing color when polished or chromium plated, and neat appearance. Copper pipe lines can be installed underground without fear of trouble except where abnormally acid conditions exist. Light gage copper tubing necessitated a fitting for joining them without cutting pipe walls for threads. Thus compression fitting introduced. Disadvantages of these fittings are high cost, clumsy appearance and inability to withstand high pressures set up during severe frost. Capillary fittings patented in '14. In this type of fitting capillary attraction, a force stronger than gravity, is utilized. No. of tests made by National Research Lab. show that joint is stronger than pipe.—*H. E. Babbitt.*

Servicing and Testing Meters. Marshall S. Dutton. Am. City. **55:** 7: 70 (July '40). Early in '39, new meter testing equipment purchased for water dept. of Oak Park, Ill., to service its 12,000 meters. Test bench and calibrated tanks have justified themselves in permitting precision work when meters are cleaned and repaired. Repair men started to demand 85% efficiency on ⅝" meters, but now anticipated that 95% efficiency will soon be had. Use of compound and current type meters on services of 3" and larger has been abandoned and, as rapidly as possible, being replaced with 2" disc meters either singly or in batteries. New methods employed have benefited dept. in many cases but more importantly have resulted in satisfied cus-

tomers. Seeking leaks on premises and satisfactorily explaining them to customers have had a part in program also.—*Arthur P. Miller.*

Water Meters, Testing and Maintenance. ANON. Southwest W. W. J. **22**: 8: 16 ('40). In '36, Houston, Tex., water dept. rebuilt 8,378 $\frac{5}{8}$″ and $\frac{3}{4}$″ water meters at approx. cost of \$3.17 each, labor cost being \$0.86. Believe that testing and maintenance of domestic water meter must be recognized as continuous operation, that max. period between tests for $\frac{5}{8}$″ and $\frac{3}{4}$″ meter should not be more than 5 yr., and that skilled mechanics are required. Unit cost of testing meters in field is \$.99 each, and analysis of 4,520 disclosed 92.6% registering accurately, with 6% under- and 1.4% over-registering.—*O. M. Smith.*

Cleaning Meter Casings by Sand Blasting. W. R. LA DUE. W. W. & Sew. **87**: 260 (June '40). Description of sand-blasting box for use in meter shop. Box designed to permit continuous vision of operations. Purpose is to prevent silicosis. Details and sketch given.—*H. E. Hudson, Jr.*

Meter Practice at Grand Rapids. ANON. Eng. News-Rec. **126**: 37 (Jan. 2, '41). Practically 100% of 40,000 services metered—only such services as those for fire sprinklers and street and sewer flushing are not. Schedule of meter removal for testing adopted 3 yr. ago. At that time some meters had been in service 40-50 yr. but now only small percentage in service longer than 5 yr. remain to be brought in and tested. Meters read every 3 mo. and readings recorded on 4″ x 8″ pages in loose-leaf book with space for 28 entries (7 yr.). To facilitate subtracting, readings start at bottom of sheet. In event of occupant being absent, card is left on which customers can record reading. If this is ignored, min. bill rendered and case dropped until next reading date, when drastic action is taken if reader cannot gain access. When unaccounted-for water increased to 34% a few yr. ago, leak survey was made and about 0.35 mil.gal. of leakage discovered at cost of \$2,500. Dept. then purchased detector of vibrator type and during last 2 yr. additional 0.6 m.g.d. of leakage has been discovered. When practice is to ground house wiring to water pipes, as in Grand Rapids, workmen may receive severe shock when meter couplings are disconnected. As protective measure, wire bypasses around meters required. Batteries of small meters more satisfactory to all concerned than single large meter. Readiness-to-serve charge on 6″ meter is \$312 per yr. and only \$22.40 on each of nine 2″ meters which will pass equivalent amount of water. Many local companies utilize deep wells for water supply for air-conditioning. As result, ground water level has been lowered 17′, with deleterious effect on shade trees. In addition, salt water encountered, and water is corrosive to piping systems and sewers. Increased salt content of river water has led to complaints from cattle owners downstream. City Commission ruled recently that well water for air-conditioning systems must be returned to ground. This is usually effected through new well at least 20′ from supply well.—*R. E. Thompson.*

The Results of a Checkup of Water Meters at Zagreb. VLATKO DABAC. Gas. u. Wasserfach. (Ger.) **84**: 9 (Jan. 4, '41). State requirement for new meters is error of 2% or less and starting sensitivity of 2% of nominal capac. Since '36 city administration has used stricter conditions of German standards with starting sensitivity of 1%. About 70% of meters still of older types. Ave. error of older meters 6.97% short; of newer meters only 0.97%. Ave. error of meters in center of old city much smaller than that of meters in newer outlying districts, where load per meter was much smaller. On other hand, leakage survey showed much higher percentage of leaking house installations in old city than in outlying dist. Calculations given show that it pays to replace old meters by new ones as additional income from more correct metering is higher in 10-yr. period than cost of meters. Low water prices have the effect of delaying necessary repairs on leaky house installations.—*Max Suter.*

WELLS AND GROUND WATER

Principles of Underdrainage as Applied to the Control of Ground Water in Engineering Works. J. Brierley. Wtr. & Wtr. Eng. (Br.) **42**: 356, 370 (Oct., Nov. '40). Owing to frictional resistance offered to movement of subterranean water, water table assumes curved form. Its inclination with horizontal plane is termed water gradient, which varies with local geological conditions. Height of water table in any district governed by lowest levels at which subterranean water can escape or "overflow" at surface. When amount of pore water in sedimentary and granular materials becomes excessive, and there is surplus in confined area over that required to fill pore spaces, water pushes particles of sand, clay or silt apart, so that they lose contact with each other and are held in suspension. Nature and texture of strata play important part in distribution of ground water. Test borings and trial pits are, perhaps, most reliable sources of information for ascertaining true level of water table at any point. Geophysical electrical methods may be used to determine existence and position of ground water. Dry and a waterlogged media will have different electrical resistivities, which gives clue to determining position of water table. Majority of problems of eng. works below ground water level would be eliminated if level of water table was lowered to below that at which works are to be constructed. When designing underdrainage systems, several methods of arranging drains, but four—herringbone, gridiron, double main and composite—usually used for large areas of land. Not essential that underdrainage system be capable of draining all water at its max. rate of discharge from interstices of strata. When dealing with cuttings and embankments, always advisable to take precautionary measures against landslides. Common practice to lay drain longitudinally along either center of cutting or in duplicate along foot of each slope. When dealing with ground where landslide has already taken place, cutting is source of weakness against sliding. Most failures of retaining walls can usually be attributed to increased pressure of ground water behind wall. Now 3 systems for lowering ground water: (1) shallow or wide well; (2) deep well; and (3) wellpoint. First consists of perforated pipe about 6″ in diam. in borehole. Annular ring between pipe and borehole casing filled with graded gravel and casing withdrawn afterwards. In second system, step sinking by shallow wells superseded through development of submersible pump. Consists of sinking pipe into borehole, which should be large enough to accommodate submersible pump, which may be 15″ to 20″ in diam. Several types of wellpoint equipment which resemble each other in principle. Wells consist of no. of vertical pipes connected at tops to a main horizontal suction pipe. Wells are spaced at 5′ to 6′ intervals.—*H. E. Babbitt.*

The Measurement of Very Small Velocities of Ground Water by Electrical Methods. Karl Schweigl and Volker Fritsch. Gas u. Wasser. (Ger.) **83**: 481, 501 (Sept. 28, Oct. 5, '40). Electrical conductivity of water measured between 2 platinum electrodes attached to quartz bridge, having gap of about ½″. Rainwater has low conductivity. Increases rapidly on passing of water through humus layer, then decreases in rock, through adsorption, but later increases again by solution of rock material. Many possible variations from this general rule, owing to local and geological conditions. Changes in conductivity are greatest in direction of highest velocity, which is also direction of steepest gradient of ground water surface. Measurements made with 8″ center well and 2½″ auger holes spaced 2′ to 10′ from center well. Care must be taken to avoid surface contamination. Measuring instrument either lowered into auger holes or water pumped therefrom and tested in lab. Latter method requires special precautions in sampling and in

handling of sample. To increase sensitivity, sodium chloride or ammonium chloride added to main well and time of increase in conductivity of water in auger holes observed. Velocity calculated gives combined velocity of diffusion and flow. Velocity of diffusion measured in special tanks with standing water. This velocity of diffusion found in open water to be about 8″ per hr., but through sand it reduced to 2″ to 4″ per day. Therefore only to be considered in very small velocities of ground water stream. Method applied to field where such small velocities existed (4″ to 5″ per day). To measure these, necessary to increase velocity of flow by siphoning from one well. By measuring amount of withdrawal, and determining lateral width of influence on ground water stream, proportional increase in velocity between closely spaced auger holes could be calculated and used as correction factor between observed and true velocities.—*Max Suter*.

Calculated and Observed Amounts of Ground Water. G. THIEM. Gas u. Wasser. (Ger.) **83:** 509 (Oct. 12, '40). Fundamental law of flow of ground water is that by Darcy, which, in its modified form, is $Q = \epsilon i a$, where Q is amt. of water flowing through given area at right angle to direction of flow; i is natural slope of surface of ground water; a wetted area; and ϵ is defined as "unit yield, that is amount of water passing through unit of area in unit of time at slope 1. Permeability thereby expressed by a definitive amount of water." Further stated that "ϵ is a volume and that i and a are numbers." [Definitions are not clear, as they do not satisfy dimensional analysis. a is defined as area and, as such, has dimension L^2 and cannot be called a number; then ϵ must have dimension L/T, which is a velocity, dimension ordinarily attributed to permeability. ϵ cannot be volume without having dimension $1/T$ somewhere else. Would be high time to get these units once straight in literature.] Values of i and a obtained from geologic data and ground water contours; Q measured during well test at steady hydraulic conditions, whereby width w of affected ground water stream also determined. a is then dw and ϵ can then be calculated from $\epsilon = Q/idw$. Determination of w requires many observation wells. Formulas therefore developed that allow calculation of ϵ from drawdown curve of test well. Method is as follows: 3 observation wells are sunk spaced at corners of an equilateral triangle. From observed ground water elevations is determined direction of static ground water flow. Observation well with lowest ground water elevation used as test well. Upstream from it and in direction of flow are sunk two closely spaced observation wells. If during pumpage of Q from test well, closer of these latter observation wells, at distance a_1 has water depth of h_1, and farther at distance a_2 has water depth h_2, then

$$\epsilon = \frac{Q(\ln a_2 - \ln a)}{\Pi(h_2^2 - h_1^2)}$$

For artesian water, formula transfers to:

$$\epsilon = \frac{Q(\ln a_2 - \ln a_1)}{2\pi t(h_2 - h_1)}.$$

where t is thickness of water-bearing strata. Two methods for determination of ϵ give results within 20% error. With knowledge of ϵ, i and a as well spacing, safe yield of well can be calculated. Several examples of application of ϵ method given, and shown that the calculated safe yields correspond very closely to actual yields of developed wells.—*Max Suter*.

Amount of Flow and Physical Phenomena in Natural and Artificial Soil Layers. LELAND K. WENZEL. Gas u. Wasser. (Ger.) **83:** 150 (Mar. 30, '40). Report of papers on ground water submitted to section of hydrology at assembly of International Union of Geodesy and Geophysics. Includes investigations by Tison and Heyndrick of changes in water levels in wells made on model of valley in Belgium; studies by Lundbye on penetration of lake water into ground water at island of Bornholm (Denmark); tests and theoretical studies on inflow of water into wells by Vibert, in France; investigations by Gosselin and Schoeller

of inflow into artesian wells, in Tunis, considering laminar and turbulent flow; report on co-ordination of observed yields and yields calculated with Dupuits formula, by Thiem, in Germany; recommendations of replacement of Dupuits formula by those of DeGlee and of C. V. Theis, by Staggewentz and von Ness, in Holland; and report of distribution of humidity in upper soil layers by Ostromecki, in Poland. Summarizing are shown different methods of measuring and expressing permeability. Hope expressed that some day, internationally usable unit for permeability, that will allow comparison of different values found, can be standardized.—*Max Suter*.

Vertical Infiltration and Filtrating and Its Significance for Protective Zones. M. Knorr and R. Muselmann. Arch. f. Hyg. (Ger.) **123:** 349 (Mar. 10 '40). Many tests made in natural ground and in pipes on vertical flow of water, bacteria, salt and dyes through ground. Experimentally, found that large pipes (over 4″) have to be used to eliminate effect of flow along pipe wall. Specially constructed double cylinder bottom was used for many pipes. Results in natural soil were similar to those in pipes, when soil was thoroughly tamped during filling. Dry and non-saturated soil can completely hold back large numbers of bacteria although water flows through. In saturated soil, bacteria are not much retained, but flow through with velocity of water. Similar differences in two types of soil humidity exist for flow of salt and dyes. Both are retained, to great extent, in non-saturated soil, even by periodic wetting; but they are completely washed out by passage through saturated soil. Salted dye solution gives best indication of infiltration flow due to its high specific gravity. Time of beginning of appearance corresponds better with calculated velocity than period of peak load.—*Max Suter*.

Quantitative Determinations in Investigations of Flow of Ground Water With Dyes and Salts. K. Kisskalt. Arch. Hyg. Bakt. (Ger.) **125:** 29 ('40); Wasser. u. Abwas. (Ger.) **39:** 4 ('41). Rock salt does not diffuse fan-wise. Even after traveling 700 m. it remains in section 1 sq.m. in diam. Sources of ground water can be distinguished by using NaCl, uranin and PhOH. Direction and velocity of flow of ground water varies with time of year.—*C. A*.

A New Indicator for Ground Water Flow. H. O. Hettche. Arch. Hyg. Bakt. (Ger.) **125:** 39 ('40); Wasser. u. Abwas. (Ger.) **39:** 4 ('41). PhOH added to sewage to test for pollution of ground water supply. Tested samples chlorinated and tasted; 0.002 mg. per liter of PhOH detectable.—*C. A*.

Phenol in the Determination of the Flow of Ground Water. B. Weber. Arch. Hyg. Bakt. (Ger.) **125:** 41 ('40); Wasser. u. Abwas. (Ger.) **39:** 3 ('41). PhOH can be used with uranin and NaCl in simultaneous detn. of several ground water relationships. PhOH preferred for study of ground water in acid soils.—*C. A*.

Ground Water Conditions in the Quaternary Sediments of the Ruhr District. Gerhard Keller. Gas u. Wasser. (Ger.) **83:** 533 (Oct. 26, '40). Ground water defined as any continuous body of liquid water below ground surface. Considered not only from standpoint of a source of water supply but also in hydrological connections and influence on mining and on deep construction work. Different geological formations described with maps and profiles as alluvial plains and glacial low, middle and main terraces with loess and sand coverings. Each of these may have water or they may be practically dry. Not geologic type that determines presence or absence of water, but type of material that underlies it and existence of local obstructions to flow. Ground water level in low terraces influenced by river stages. Shown that, during high river stages, river water can and does flow into ground water.—*Max Suter*.

Successful Search for Ground Water With the Help of Geophysical Methods. Willy Rathe. Gas u. Wasser. (Ger.) **83:** 369 (Aug. 3, '40). At Greifswald on Baltic Sea nearly impermeable cre-

taceous rocks are overlain by irregular diluvial deposits. Ground water can be found in certain places of glacial deposits, but its occurrence is spotty. Geologic studies of well records show that surface of cretaceous rocks is irregular and shows no relation with present surface of moraines. Good ground water can be found only in old filled valleys of cretaceous rock base. Electrical-resistivity surveys were made to locate these, using method with d.c. Standardization of electrical apparatus showed that resistance reduces sharply when depth of rock is reached, probably due to salt content of small amount of water in it. First measurements were made by geophysicist, but local personnel was trained in handling of apparatus and geophysicist called in only for interpretation of results. Method allowed mapping of whole surface of cretaceous base and showed existence of buried valley which could be used for new water supply. Cost of electrical method was less than $\frac{1}{10}$ of estimates for thorough exploration of territory with drill holes. Time required was reduced to 7 mo. compared to estimated 30 mo. needed to sink drill holes.—*Max Suter.*

Contamination of Ground Water Resources. Burt Harmon. Civ. Eng. **11:** 343 (June '41). Many types of industrial waste which, when introduced into underground supply, will force its abandonment for domestic use. In Pacific Southwest, where stream beds may be totally dry for 8 or 9 mo. in yr., attempt to trace contamination to source may develop into problem that, to use army phraseology, "has no approved solution." In '27, series of sumps constructed along east bank of Los Angeles County Flood Control Channel about 3.5 mi. from ocean, for purpose of reclaiming such oil as remained in waste waters. Attention called to possible danger arising from operation of sumps, when private wells more than $\frac{1}{4}$ mi. west of channel were becoming too salty for use for irrigation. Contamination spread slowly, but not uniformly, on both sides of channel. In some cases, increase of salinity of wells gradual, and in others very rapid. Test holes showed ground water with varying degrees of chlorine concentration, but of such irregular occurrence that hopeless to attempt to trace source. Tests did show conclusively that bottom and sides of unlined ditch not sealed by drilling mud and oil emulsions carried by waste waters. While portion of solns. that percolate into loose sands of channel of Los Angeles R. may be carried to sea by infrequent floods, studies in Long Beach showed that most do not remain in channel to be washed away, but penetrate great distances in all directions. Cities of industrial dist. lying south of and adjacent to City of Los Angeles have pop. of approx. 100,000. Water supply of this area entirely from deep wells. No indication that contamination has yet percolated to underground water supply. Nevertheless, menace there. Procedure followed by oil companies in Santa Fe Springs-Whittier-Montebello dist. for disposal of waste waters points to logical solution—piping of such wastes to sea instead of utilization of stream beds as industrial sewers and of water-bearing gravels as cesspools.—*H. E. Babbitt.*

On the Pollution of Ground Water by Chemicals. Alexander Lang and Hayo Bruns. Gas u. Wasser. (Ger.) **83:** 6 (Jan. 6, '40). Examples of pollutions in Rhine and Ruhr valleys are described. Wastes of a picric acid plant leaked into ground water. In 5 to 6 yr. picric acid could be found in wells located about 3 mi. downstream and about $\frac{1}{2}$ mi. from Rhine. Plant to granulate slag from blast furnaces by chilling molten slag in a water stream and settling in basins caused rise in temp. in wells located 2000′ downstream. Hardness, iron and manganese increased. Fluorescin and *Bacillus prodigiosus* were used to prove direct connection from basins to wells. Velocity of ground water stream in the gravel was about 33′ per hr. About 25 to 30 yr. ago, ashes and garbage were dumped in an old sand pit reaching below ground water level. After several years pollution was found in wells located 2000′ away from pit by an increase in hardness, iron and manganese content and appearance of

tastes. Although pit has not been used as dumping ground for 15 yr. and is transformed into a park, pollution still exists. Waste pile from a coal mine caused an increase in sulfate hardness and in iron and manganese in wells located within 100′ from Ruhr and which are pumping mainly bank filtered water. Leaky tile effluent line of a sewage treatment plant using chlorination cased phenol tastes and fungi growth in wells located 300′ upstream of plant. Fluorescin put into this effluent line showed up in wells in 24 hr.—*Max Suter.*

Contamination of Water Wells by Salt Water. PENN LIVINGSTON. Tex. W. W. Short School **21:** 28 ('39). Contamination may have any of three sources: (1) by encroachment of salt water into fresh water-bearing formation, rate of encroachment through sand being slow but once salt water has permeated fresh water-bearing beds they seldom freshen again; (2) by salt water that seeps into well through faulty or corroded casing from salt-water stratum through which well passes; and (3) from some defective well near by. Character and positions of these salt water leaks may be determined by: (1) pumping; (2) using a deep well meter to measure movement of water in well; (3) determining conductivity of water; and (4) sampling and analyses. In most of areas in Texas in which salt water has developed, wells have been contaminated because of defects in wells themselves, a much less serious condition as far as the whole community is concerned.—*O. M. Smith.*

Fluorine in the Underground Waters of the Khibin Region. I. N. ZAY'YALOV. Compt. Rend. Acad. Sci. (U.S.S.R.) **26:** 232 ('40). Analyzing, comparing and summing up values of F content and of pH in (*a*) surface waters, and (*b*) underground waters from (*i*) quaternary deposits, (*ii*) country rocks and (*iii*) mixed waters, led to following conclusions: (1) (*a*) with exception of (*i*) are on ave. much poorer in F than (*b*) and also show lower pH value; (2) in (*i*) ave. F content is 0.10 mg./liter, pH, 6.6; in (*a*) ave. F content is 0.16 mg./liter, pH, 6.6; in (*iii*) ave. F content is 0.20 mg./liter, pH, 7.7; in (*ii*) ave. F content is 0.47 mg./liter, pH, 8.3. These facts confirm assumption that sources of enrichment are country rocks, rich in F-bearing minerals (apatite); but country rocks are not uniformly impregnated by F-bearing minerals.—*C. A.*

Removing Sand from Well Water. J. B. DANNEBAUM. Southwest W. W. Jour. **22:** 19 ('40). All experiments tried on well water at Houston, Tex. on sand settlement devices, using decreases in velocity of flow or gravity, have been rather futile; and quantities of sand have been deposited in mains in certain sections. Problem was to find unit that would handle flows up to rates of 15 m.g.d. through 200 mesh screens with head loss not exceeding 10′ when handling normal amts. of sand. "Brassert Automatic Strainer", 24″ size rotated by a 5 h.p., 220 v. motor is used and each unit contains 2,528 screening discs of 200 mesh stainless steel screen. These are backwashed twice weekly to dislodge grains of sand which are lodged between wires of screen. Continued troup-free service is expected from units; investment will save thousands of dollars annually in meter maintenance.—*O. M. Smith.*

The Importance of Grouting in Wells. O. J. MUEGGE. Wisconsin State Bd. of Health Bul. **6:** 14: 16 (Apr.–June '39). Proper well construction will reduce or eliminate bacterial contamination of ground waters, but will not necessarily eliminate toxic substances such as lead, fluorine, etc. Knowledge of manner in which wells become contaminated, together with proper well construction to prevent contamination, is necessary. Author discusses manner and methods of ground water contamination and gives resumé of bacterial action in soil. Utilization of cement grout in well construction may effectively be employed as follows: (1) to seal annular opening surrounding well casing to prevent pollution or to maintain an artesian development; (2) to protect casing pipe against external corrosion,

thereby prolonging length of usefulness of well; (3) as a well casing material, used alone or as reinforcement of inadequately jointed or lightweight material; (4) for settling of casing terminals in rock formation. Outbreaks of disease resulting from neglect of applying these 4 points are listed. Detailed description of manner in which grout should be placed given. Must be placed properly to be effective. Has been demonstrated as being an effective aid in production of more permanent safe water supply. —*P. H. E. A.*

Well Casing Depth Detector. HANFORD THAYER. Eng. News-Rec. **124:** 531 (Apr. 11, '40). Simple, inexpensive device illustrated consists of a window weight with fingers of No. 9 galvanized wire fastened to it. Weight is lowered to bottom of casing by means of insulated wire, one end of which is connected to post of automobile battery. Other post of battery is connected through 6-volt bulb to well casing. Light grows dimmer as resistance increases and circuit is broken when fingers are below bottom of casing. To avoid fouling, fingers should be long enough to pass gradual bends, and their ends should be brought to center. Window weight of poor grade cast iron should be employed so that, in event of loss, it can be broken up easily with a drill. Device has been used successfully in well more than 800′ deep.—*R. E. Thompson.*

Analysis of Legal Concepts of Subflow and Percolating Waters. C. F. TOLMAN AND AMY C. STIPP. Proc. A.S.C.E. **65:** 1687 (Dec. '39) (*see* Jour. A.W.W.A. **32:** 891 ('40); **33:** 198 ('41)). *Authors' Closure. Ibid.* **67:** 433 (Mar. '41). Eng. instruction in most colleges does not treat, adequately, laws and principles governing occurrence and motions of underground water. Advances in ground water hydrology from '20 to '40 have not as yet modified erroneous concepts on which earlier (legal) decisions founded. Doctrine of rights by appropriation has received support by many engrs. and lawyers. General ground water equation, which evaluates rainfall, runoff, evaporation, and transpiration, can be applied better in East than in the desert region where these factors are more variable. Existence of water table below bottom of influent stream proved by measurements of depth to water table in test holes sunk in stream bottom within area covered by water.—*H. E. Babbitt.*

Artesian Versus Surface Supply—Ogden River Project. RALF R. WOOLLEY. Civ. Eng. **11:** 536 (Sept. '41). To augment water supply of some 19,250 acres of cultivated land in vicinity of Ogden and Brigham, Utah, primary purpose of Ogden River project. Also assures city of Ogden annual storage of 10,000 acre-ft. of water for supplemental municipal and irrigation uses. Principal construction feature Pine View Dam, creating reservoir to store 41,800 acre-ft. at the head of Ogden Canyon, about 7 mi. from Ogden. Unique feature of project is preservation and maintenance of Ogden's artesian wells in Artesian Park to function without regard to surface reservoir even when park area is submerged to depth as much as 40′. Before construction of Pine View Dam, 146 wells located within Ogden Valley. About 80 flowing wells, of which 51 situated in Artesian Park, with depths ranging from 85 to 600′ and diam. from 2 to 12″. To obtain records of fluctuation of ground-water levels and information relative to material in valley fill, 6 test wells drilled in '32 by U. S. Geol. Survey. In '29, agreement signed by appropriators and users of water from Ogden R. and tributaries for purpose of composing and permanently settling all disputes, controversies, and litigation over water rights. At present, matter of defining and fixing water rights under study by court-appointed board, consisting of State Engr., Judge of Dist. Court of Weber County, senior in age, and two disinterested geologists and one disinterested engr. Important detn. of decree is whether or not use of city's wells affects flow of Ogden R.—*H. E. Babbitt.*

Utah Submerged Well Field Continues to Supply Water. ANON. W. W. Eng. **93:** 241 (Feb. 28, '40). Water supply of Ogden, Utah, obtained from 47 artesian

wells now submerged as much as 55′ under waters of Pine View Res. on Ogden River. Max. natural discharge of wells before submergence 17¼ sec. ft., and 20 sec. ft. when auxiliary air-lift used. After submergence natural flow increased to 24 sec. ft. Continued use of wells obtained by undercutting 47 of wells approx. 9′ below original outlet, collecting flow through steel pipes into 3 steel collection mains (max. diam. 20″) emptying into steel collector tanks, then through 9000′ long 38″ all welded steel pipe to city mains at location just below dam. All pipes 4′ to 13′ below res. bed. Submerged system has operated satisfactorily for 3 yr.—*Martin E. Flentje.*

Compact Water System Built Around Radial Well. Anon. Am. City. **55:** 12: 56 (Dec. '40). To augment water supply of Penns Grove, N. J., Ranney collector system was installed in gravel formation several acres in extent, 1 mi. east of town. Collector consists of concrete caisson (13′ inside diam.), sunk to depth of 33′ with pipe inlets and valves for 12 laterals or radial wells, ranging from 3′ to 9′ above bottom. 8″ pipes were jacked radially through inlets to distances of 30′ to 113′, depending upon resistance encountered. As these slotted pipes were forced outward, 2″ sand discharges inside drew out inflowing sand, leaving screens surrounded by gravel and thus increasing water flow. Only 7 radial wells were driven at this time and only 1 pump was installed, although 12 wells can be driven and two more pumps installed. Lime in suspension is added to water at discharge ends of each of wells and chlorine is used for disinfection, being applied to water on discharge side of pump just ahead of meter.—*Arthur P. Miller.*

Deep Well Solves Critical Water Problem on the Northern Pacific. E. M. Grime. **37:** 338 ('41). Water supply for Dilworth Terminal of Northern Pacific R. R. near Gantz, Minn., formerly secured from Buffalo River, with 2 supplemental reservoirs holding 77,000,000 gal. Dry weather caused annual water shortage and, in dry periods, dissolved solids in softened water frequently as high as 65 g.p.g., causing foaming trouble in locomotives. 22″ and 17″ well installed 265′ deep by mud-laden fluid method in glacial drift, with 12″ casing and strainers and water bearing strata reamed to 42″ and gravel packed. 28¼ cu.yd. gravel used. Well developed to deliver 365 g.p.m. with drawdown of 197′. Five-stage submersible type centrifugal pump used with 40 h.p. motor. Well water contains no non-carbonate hardness; and dissolved solids in softened water remain uniformly at 17 g.p.g.—*R. C. Bardwell.*

Newmarket (Ontario) Increases Water Supply With Additional Deep Well. Anon. Eng. Cont. Rec. **54:** 23: 8 (June 4, '41). Water supply of Newmarket, 4,000 pop., derived from 5 wells in 3 locations. Demand from military camp and recent bldg. activities increased consumption from 195,000 to 300,000 g.p.d., rendering imperative new source of supply. New well of under-reamed, gravel-wall type under construction. Capacity expected to be 288,000 g.p.d. 20″ boring being drilled with all-electric rotary drill, drill cuttings being removed by liquid mud pumped down hollow drill shafting and out through orifices in cutting tool. Mud overflows from top of boring and is re-used after heavier cuttings have settled. On reaching water-bearing stratum, 14″ welded steel casing will be inserted and annular space between casing and well wall filled from bottom up with neat cement. This will protect casing from corrosion and reduce possibility of contamination. Under-reaming will then be carried out and shutter-screen barrel inserted, followed by 8″ inner lining pipe. Bottom of screen will be sealed off with neat cement. After gravel (Cape May) wall has been placed around screen, 8″ inner lining pipe will be replaced by mechanical parts of vertical turbine to be connected immediately above shutter screen.—*R. E. Thompson.*